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Hydrologic Engineering Center

PROCEEDINGS OF A

Hydrology & Hydraulics Workshop

on

Risk-Based Analysis for Flood Damage Reduction Studies

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A workshop on Risk-based Analysis for Flood Damage Reduction Studies was held on 20-22 October 1997 at the Asilomar Conference Center in Pacific Grove, CA. Policy issues, case example applications of procedures, a risk-based analysis computer program, and levee certification criteria for regulatory floodplain management actions were covered in the sessions. The workshop provided a forum for exchange of ideas and perspectives on ongoing risk-based analysis for flood damage reduction studies. It also provided an opportunity to assess the progress made since the Montecello, MN. Riverine Levee Freeboard Workshop, held in 1991. The objectives of the workshop were to: 1) review the present policy and procedures for performing risk-based analysis studies; 2) identify key isses and discuss their means of resolution; and 3) define and discuss Corps procedures and requirements for levee certification. The workshop proceedings are contained herein.

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FOREWORD

The Hydraulics and Hydrology Branch, HQUSACE, and the Corps Hydrology Committee cosponsored a workshop on *Risk-based Analysis for Flood Damage Reduction Studies*. The workshop was held on 20-22 October 1997 at the Asilomar Conference Center in Pacific Grove, CA. The Hydrologic Engineering Center (HEC) was responsible for the technical program and workshop coordination.

Policy issues, case example applications of procedures, a risk-based analysis computer program, and levee certification criteria for regulatory floodplain management actions were covered in the sessions. The 21 participants presented 13 technical and six panel discussion topic papers. Corps participants included representatives from Headquarters, Divisions, Districts, the Institute for Water Resources, and the Hydrologic Engineering Center. Non-corps participants were from the Sacramento Area Flood Control Agency, the Federal Emergency Management Agency, the Association of State Flood Plain Managers, Michigan State University, and the private sector.

The workshop provided a forum for exchange of ideas and perspectives on ongoing risk-based analysis for flood damage reduction studies. It also provided an opportunity to assess the progress made since the Monticello, MN. *Riverine Levee Freeboard* workshop, held in1991, that is considered the forum that initiated risk-based analysis procedures for flood damage studies in the Corps. The primary objectives of the Asilomar workshop were to: 1) review the present policy and procedures for performing risk-based analysis studies; 2) identify key issues and discuss their means of resolution; and 3) define and discuss Corps procedures and requirements for levee analysis.

RISK-BASED ANALYSIS
for
FLOOD DAMAGE REDUCTION STUDIES

EXECUTIVE SUMMARY

INTRODUCTION

A workshop on *Risk-based Analysis for Flood Damage Reduction Studies* was held on 20-22 October 1997 at the Asilomar Conference Center in Pacific Grove, CA. Policy issues, case example applications of procedures, a risk-based analysis computer program, and levee certification criteria for regulatory floodplain management actions were covered in the sessions. The workshop provided a forum for exchange of ideas and perspectives on ongoing risk-based analysis for flood damage reduction studies. It also provided an opportunity to assess the progress made since the Monticello, MN. *Riverine Levee Freeboard* workshop, held in1991. The objectives of the workshop were to: 1) review the present policy and procedures for performing risk-based analysis studies; 2) identify key issues and discuss their means of resolution; and 3) define and discuss Corps procedures and requirements for levee certification. The workshop proceedings are contained herein.

BACKGROUND

The Corps of Engineers applies risk-based analysis procedures in formulating and evaluating flood damage reduction measures. The procedures address the requirement of the Office of Management and Budget (OMB) to meet the 1982 *Principles and Guidelines* standard for federal agencies to apply risk and uncertainty procedures in the evaluation of water resources projects. Federal funding for implementing the Corps flood damage reduction project/proposals are now developed by applying risked-based analysis procedures.

The Corps policy and analytical methods for incorporating risk-based analysis in flood damage reduction studies were largely the offspring of the *Riverine Levee Freeboard* workshop held in Monticello, Minnesota in 1991. Though focused on levee sizing, freeboard concepts, and certification issues regarding Federal Emergency Management Agency's flood insurance regulatory policy, the results of the workshop were soon broadened to include the full complement of flood damage reduction measures and actions. Policy actions followed including a draft Engineering Circular 1105-2-205 in 1992 entitled *Risk-Based Analysis for Evaluation of Hydrology/Hydraulics and Economics in Flood Damage Reduction Studies* which was finalized in 1994 and upgraded to ER 1105-2-101 in 1996. Guidance was developed and presented in

Engineering Manual 1110-2-1619, *Risk-Based Analysis for Flood Damage Reduction Studies,* dated 1996.

The use of risk-based analysis quantifies uncertainty in discharge-exceedance probability, stage-discharge, damage-stage relationships and incorporates it into economic and performance analyses of alternatives. The process applies Monte Carlo simulation, a numerical-analysis procedure that computes the expected value of damage reduced while explicitly accounting for the uncertainty in the basic functions. A spreadsheet application risk-based method was presented in the 1991 workshop and afterwards was slightly modified and applied to Corps studies. Its capabilities were replaced by modern, comprehensive program released in provisional form in January of 1997. The adopted risk-based analysis procedures have undergone extensive peer review including a detailed review by the National Research Council of the National Academy of Sciences.

From 1991 through 1997 over 1300 Corps personnel have been taught the risk-based concepts in the Corps formal Prospect training courses, local workshops, seminars, and technical assistance studies. During this period over 200 studies using risk-based analysis are either underway or have been completed. They range from small project continuing authorities to major urban and watershed studies. Within this span of six years the procedures have become fully integrated into the Corps technical studies and accepted as the normal way to do business.

POLICY AND PRESENT STATUS

The initial session of the workshop focused on the evolution, present policy, and status of implementing risk-based analysis as briefly chronicled above. The Corps' risk-based analysis research and development effort and overview of the broad-scaled implementation for various study purposes were presented. The goal is to develop and apply procedures that are explicitly integrated into the formulation and evaluation process so that better engineering, environmental, and economic decisions are made. Ongoing efforts and concepts involving dam safety, major project rehabilitation, flood damage reduction, and special applications and future roles in coastal areas and navigation are overviewed.

Risk-based analysis for flood damage reduction studies provides information regarding economic investments and hydraulic project performance not previously available. It is not intended to be a substitute for good engineering. Risk-based analysis is in the formulation of the type and size of plans that meet the study objectives. The locally preferred and National Economic Development (NED) plans must be identified from the final array of alternatives. They may or may not be selected as the recommended plan. A key point made during the workshop is that the formulation process must define the residual risk associated with the plans to determine the consequences of the project capacity being exceeded. The question is not if, but when the capacity is exceeded. It should include the risk to life and economic losses. The workshop participants identified residual risk as an area needing more research and definition.

The Washington Level Review staff has approved over 30 flood damage reduction feasibility-phase reports. While study checkpoint conferences have generally shown a good technical understanding of the risk-based concepts, the adopted analysis procedures and results need to be better described and displayed in the reporting documents. Many district technical problems attributed to application of the risk-based procedures are instead ones involving the conventional plan formulation process.

PROJECT AND SPECIAL TOPIC STUDIES

Case example applications studies, geotechnical analysis for levees, communication of flood risk, special topics, and a computer program for performing the risk-based studies were covered in sessions under Project Studies. The case studies emphasized leveed major urban damage center, one of which with a major flood control reservoir immediately upstream, and urban areas involving a mix of flood damage reduction measures of levees, walls, channels and detention.

The American River Study, involving the City of Sacramento and vicinity area, was presented both from the Corps and local sponsor perspectives. Sacramento is one of the most threatened areas in the country. Approximately 400,000 people and $37 billion in property are behind by levees. Risked-based analysis was applied to analyze the uncertainty in the upstream Folsom reservoir operation, downstream conveyance, and existing levee system. The analysis enabled development of better information on risk and project performance than would be available without the risk-based methods.

The Des Plaines River study, in metropolitan Chicago, applied risked-based methods to define uncertainty in exceedance probability, stage, and damage to formulate a system of detention reservoirs and levees. A detailed presentation of the analysis and results are presented. The St. Paul and Louisville District's experiences involving a series of studies were shared during the sessions.

The communication of flood risk was identified throughout the workshop as the single-most area needing attention and additional work. A case study was presented to describe risk communication lessons learned during public participation forums and the testing of the level of understanding of local officials and the public during the conduct of the American River Study. Better communication terms and means are needed at all levels including the internal Corps technical and managerial staffs and between the Corps and local sponsors, government officials, and the public. Better communication between the Corps and others in the profession was identified by the non-Corps participants as needed. The Corps methods are likely to be adopted by others outside the Corps and can influence a variety of actions, standards, and regulations. They expressed the need for accepted peer review within the profession and to find effective means of transferring the concepts and methods to the engineering profession as a whole.

The Hydrologic Engineering Center Flood Damage Analysis (HEC-FDA) computer program for formulating and evaluating flood damage reduction plans using risk-based analysis methods was demonstrated. The program is being used throughout the Corps. It replaces the spreadsheet software initially developed in 1991. Other special topics were covered in a panel discussion. They covered a variety of topics from the headquarters, division and district perspectives.

FLOOD PLAIN MANAGEMENT

This session explored the relationship of risked based analysis and flood plain management. It covered issues related to flood risk data, flood plain delineation, FEMA certification, and Corps flood damage reduction project studies. Comparisons of previous approaches and risk-based analysis methods for defining project performance were covered. The procedures and criteria for FEMA for levee certification under the risk-based analysis approach were presented. The criteria and consequences of implementation of risk-based analysis for levee certification from the FEMA, Corps, the Association of Flood Plain Managers, and the private sector perspective were presented.

SUMMARY AND CONCLUSIONS

The workshop presented a variety papers and presentations covering a range of topics within the framework of the flood damage reduction analysis using risk-based analysis procedures. The major conclusions of the workshop are listed below.

- Significant progress in incorporating and applying risk-based analysis for flood damage reduction measures has been made since the concepts were first presented for levees in the 1991 *Riverine Levee Freeboard Workshop*, held in Monticello, Minnesota. Policy and procedural documents have been prepared, applications software developed and distributed, and numerous studies formulated and evaluated. Over 1300 Corps personnel have been trained as the procedures have now been fully integrated within the Corps organization.

- Levees and floodwalls remain an important alternative for reducing flood damage in many locations. The 1991 workshop raised several issues associated with levees including: how to deal with the concept of freeboard for new , existing, and small levees; what type of analyses are required; how to better present levee performance information to local sponsors and others; and how will eliminating the concept of freeboard effect the FEMA administration of the National Flood Insurance Program regarding levee certification? Each of these issues have successfully addressed by development and implementation of risked-based analysis policies, analytical procedures, and computer software. The concept of

freeboard has been eliminated, methods of defining uncertainty in exceedance probability, stage, damage and levee geotechnical failures are incorporated into the analysis process, and better information on economic and hydraulic project performance are now generated. Finally, the FEMA levee certification process has been updated to include risk-based analysis concepts.

- Several areas of needed enhancements to the risk-based analysis capabilities were identified. These include project costs functions with uncertainty, nonstructural measures, uncertainties for specific hydraulic adjuncts (ice, debris, bulking, etc.) to the rating function, and GIS interfaces. Output should be expanded to develop more economic related information such as number of structures flooded by zones, population impacted, etc. These additional capabilities will be considered for inclusion in future releases of the HEC-FDA program.

- Throughout the workshop, the participants expounded on the need for clearer and better flood risk communication terms and procedures. The terms and procedures may vary in scope and detail for technical analysts and the general public dissemination. One goal could be to adopt universal terminology as agreed to by an established committee of government agency, professional society, and private sector personnel.

THE USE OF RISK ANALYSIS BY THE U.S. ARMY CORPS OF ENGINEERS

David A. Moser[1]

INTRODUCTION

Water related engineering has a long history of using risk analysis methods. Hydrologic engineers are very much concerned with risks in estimating the frequency of rainfall or stream flow events. In many situations, these engineering related risk quantities establish levels of "risk acceptance." For instance, the Flood Insurance Administration of the Federal Emergency Management Agency (FEMA) has used the 100-year or 1 percent exceedance flood as their "base flood." This risk standard implies that floods that exceed this standard (lower frequency floods) are too infrequent to worry about. In other instances, water agencies have used even rarer events for design purposes. The probable maximum flood (PMF) is frequently used as the design event for spillways. Among some hydrologic engineers, the PMF is so rare that its probability cannot be established; it is the last point in the tail of the flood flow frequency distribution. The purpose of the standard is to provide an operational design criterion to meet the engineering design goal of no failures. In these cases, the consequences of the event that exceeds the standard are not explicitly considered. For the FEMA case, the residents enjoying protection against the base flood might consider themselves "safe." Giving a dam a PMF spillway assures the engineer that the dam will never fail.

For the purposes of the following discussion, the terms, risk and uncertainty, need to be distinguished. These terms are frequently confused because the same terminology is used to describe each. A common definition of risk is the likelihood of the occurrence and the magnitude of the consequences of an adverse event. Uncertainty can be thought of as the indefiniteness of some aspect of the values in the risk quantification process. The term risk usually derives from some initiating "hazard" event with uncertainty characterizing the transmission of the hazard to the ultimate consequences.

The Corps of Engineers and other entities engaging in activities that manage risk have come to recognize that this purely engineering approach to risk management is too simplistic and incomplete. More than a single risk needs to be considered. These risks may stem from other engineering or technical considerations, environmental issues, or economic performance. In addition, when factoring risks into decisions, the Corps recognizes that uncertainties about the quantities in any part of an analysis must be addressed. The reason for using risk analysis is to make better engineering and economic decisions. This is accomplished by increasing our understanding of how Corps water resources investments will perform in the future from both engineering and economic perspectives.

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[1]Economist and Manager of the Risk Analysis for Water Resources Investments Research Program, Institute for Water Resources, U.S. Army Corps of Engineers, Alexandria, VA

This does not imply that introducing risk analysis methods and thinking into a traditional engineering organization has been universally embraced. To address legitimate concerns about the necessary learning at the technical and managerial levels, risk analysis is being gradually applied in different civil works areas and the process is not complete.

The following three sections describe the agency wide usage of risk analysis by the Corps as of 1996. In the succeeding section, special applications are described. The paper concludes with a description of new directions and assessment of the Corps successes in using risk analysis.

DAM SAFETY

Civil engineers have a long interest in designing dams that can withstand unusual or rare loads due to floods. This interest in improving the reliability of engineering structures has been generally pursued by first quantifying the size of the rare event and then providing design features to assure safety. The National Research Council (NRC) report on dam safety (NRC, 1985) provides a synopsis of the evolution of design criteria for the safety of dams in the event of rare floods. The development of the notion of the probable maximum flood (PMF) represents a culmination of this evolution. This hypothetical event is considered to have virtually a zero probability of occurring. The basic philosophy of this design approach is similar to that used in regulating human health and safety risks: establish the standard at the dosage where there are no observed adverse effects. With dams, however, the adverse effects are to the dam and on humans only inferentially. Applying this "standard" to all dams ignores differences in the effects of dam failure at different sites.

Based on the NRC report, the PMF standard applied to all dams may be excessive. The report notes that "since the spillways of many existing dams are inadequate by PMF standards but have survived in spite of this inadequacy, it is legitimate to question whether this standard is higher than may be required." Additionally, the PMF inflow event is only one part of the chain of conditions assumed in designing to PMF standards. These include "conservative" assumptions about infiltration losses due to soil conditions, initial reservoir water levels, and reservoir operations. This compounding of highly risk averse assumptions may reduce the likelihood of the very rare flood to an absurdly small probability.

The problem that the Corps faced was applying the PMF standard to existing dams. Meeting the standard would require costly modifications to spillways and embankments. Risk analysis was considered as one approach to choosing whether to make a safety improving investments for any dam. One approach is to use a comparative risk analysis (Moser and Stakhiv, 1987). Under this method, accepted levels of risk to human health and safety are used as the design standard. This requires characterizing the dam safety risk by quantifying both the likelihood and the consequence of dam failure for the existing dam configuration and all modifications formulated. The fatal flaw for this approach is the wide error band for large floods calculated by extrapolating traditional flow-frequency relationship. In addition, getting beyond assigning a probability to the PMF proved insurmountable.

An alternative approach that was adopted used some ideas from risk analysis but without attempting to develop probabilities. Instead of relying on the PMF standard, the Corps defined a "base safety standard." This design standard is met ". . . when a dam failure related to hydrologic capacity will result in no significant increase in downstream hazard (loss of life and economic damages) over the hazard which would have existed if the dam had not failed." (USACE, 1985) Figure 1 shows an idealized result showing the base safety standard at less than the PMF. This policy espouses an "incremental hazard" viewpoint. Any dam modification to pass safely a PMF is excessive if a failure at a lesser flood has the same consequences as those if the dam had not failed. Thus, modifications that do not reduce the hazard or consequences of the event should not be considered further. An alternative interpretation is that it assumes the engineer should provide safety to the point that the dam does not impose an added risk compared with the natural situation. Although this approach to dam safety does use some risk analysis concepts, it does not provide information on the risk bearing by those downstream of the dam. The basic philosophy is that the engineer should not impose any added risk regardless how small. Of course without probabilities, there is no objective measure of the risk reduction produced by a modification to meet the base safety standard.

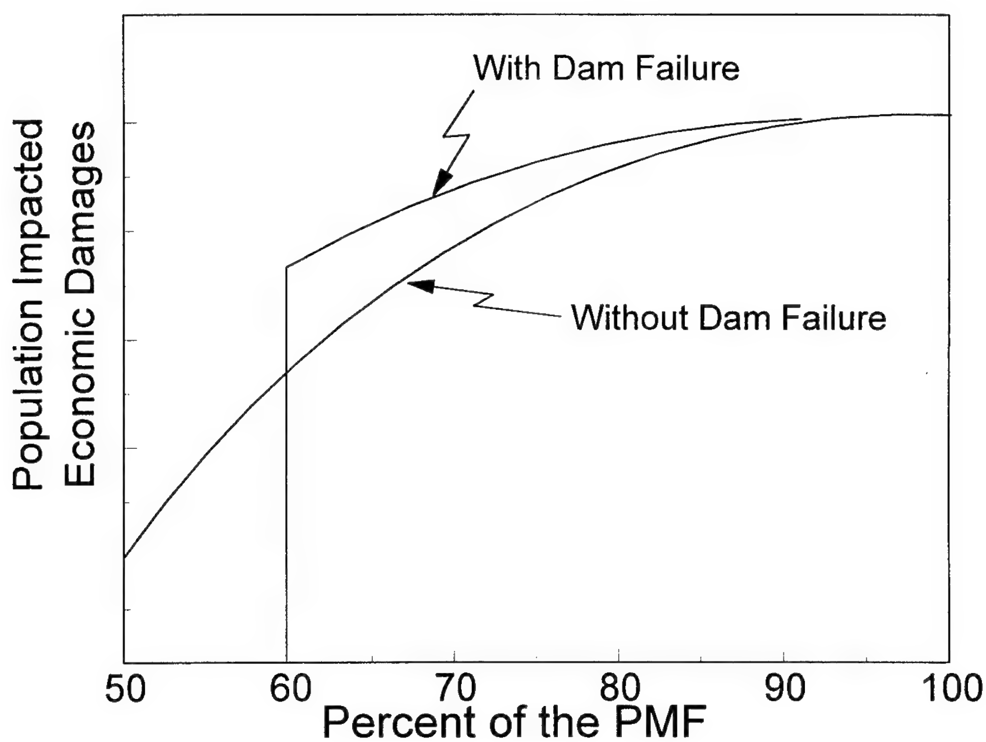

Figure 1: Determining the Base Safety Standard, USACE, 1985.

Estimating the "with and without" dam failure impacts requires quantifying the people and property at risk from various flood events. Models routing inflow floods through the reservoir and downstream routing of non-failure and failure flows are used. Characteristics of these events, especially warning time to population centers, are important in providing realistic estimates of people at risk. The procedures necessary to evaluate a dam safety hazard from rare floods are codified in USACE, 1986. These procedures describe the steps necessary to develop the input data to set the base safety standard as shown in Figure 1.

The Corps is now starting to examine its dam safety policy to consider all sources of dam failure risk, not just from rare floods. If quantifying all initiating event probabilities can be done, an overall statement of risk can be provided and the contribution to risk reduction of each dam modification assessed. Potentially, this might provide the basis for establishing a risk-based dam safety standard using a comparative risk analysis approach.

MAJOR REHABILITATION

The Corps of Engineers is responsible for managing hundreds of water resources investments throughout the United States. Many of these projects have performed successfully over many years and continue to provide valuable services to the nation. As these projects age, the years and wear and tear take their toll. Major components of projects become less reliable and are subject to both degraded service and the possibility of failure. In addition, new technology offers the potential opportunity to enhance the project outputs while addressing any reliability problems. In 1991, the Corps initiated the use of risk analysis to evaluate proposals for any major rehabilitation of water resource investments that it manages. Before that time, spending for major rehabilitation required little analysis of the likelihood or consequences of project component or feature failure. The Corps, with the encouragement of the Office of Management and Budget (OMB), recognized that major rehabilitation is an investment to avoid future increased operating and emergency repair costs and losses in project outputs due to emergency repairs. To implement the program, the Corps developed an economic-based decision framework that borrows heavily from the methods of risk analysis combined with probabilistic benefit-cost analysis (USACE, 1996).

Quantifying future project component or feature reliability is fundamentally an engineering problem. For investment and rehabilitation decision making, however, the consequences of future unreliable engineering performance must be related to economic consequences and the economic performance of the project being evaluated. To help identify the linkages between risk and consequences, analysts must use standard risk analysis tools such as event trees and fault trees. These trees are frequently used together to expose the process of transmitting risks to consequences and to identify required contributions from each member of the study team.

To place this into a benefit-cost framework requires the establishment of the "with and without" project condition. Since the project is already in operation, the "without" project condition is "without" major rehabilitation, defined as the base condition. Completing the analysis requires a determination of the response to actual breakdowns and an assessment of the economic costs during

these "unplanned" situations. Major rehabilitations reduce the frequency of these breakdowns, the cost of the breakdowns or both. Besides reducing future project costs, major rehabilitations offer the opportunity to restore project efficiency lost since original construction and to increase project outputs beyond the original design. Therefore, the economic benefit of rehabilitation is composed of the reduced future costs and the value of increased future project output. Rehabilitation costs obviously contain the cost of constructing the rehabilitation alternative chosen. Less obvious is the cost in the form of lost project outputs during the time that the project is closed during the rehabilitation. This last cost is frequently overlooked but also can be reduced by careful planning and scheduling of the construction.

A life-cycle approach was adopted in recognition that a major rehabilitation makes a sure investment that must be balanced against uncertain, future reductions in costs and increases in output. Additionally, component reliability may change with time and usage. The variable of interest is the present value of rehabilitation benefits. Analytical or simulation models must be employed to evaluate the base condition and all rehabilitation strategies to predict benefits. Typically, Monte Carlo simulation models have been developed or adapted to estimate the distribution of life-cycle benefits. Initially this involved the use of general purpose tools such as spreadsheet macros and spreadsheet Monte Carlo simulation add-ins such as @RISK by Palisade and Crystal Ball by Decisioneering. As problems become more complex, special purpose models have been developed.[2]

Quantifying the reliability of engineering features and components has required adaptation and development of new methods. The initial approach, at least for structures, used a reliability method for quantifying a reliability index of a component or feature. This method relied on the availability of models predicting the safety factors for features of interest. The capacity and demand aspects of the safety factor model are based on values of input variables such as thickness of metal and unit weight of concrete. Any uncertainty in these input variables will result in an uncertainty in the safety factor. This approach only provides a snapshot of the reliability of the feature. Because a major rehabilitation changes the future reliabilities, a weak link in the reliability index method is its inability to forecast future reliabilities. To develop time or usage dependent reliabilities, capacity models containing time or usage variables are being developed to replace the reliability index method. For components with systematic records of failure, survivor analysis is used to estimate a hazard function for a component. The hazard function provides the age or usage dependent risk quantities required for a life-cycle analysis. This approach has been applied to hydroelectric generating unit components.

Quantifying the monetary values of operations and maintenance cost, repair costs, project outputs, and rehabilitation costs are straightforward. Estimating the uncertainties in these values is currently not required. However, in the future, these additional uncertainties may be added to the analysis.

The current policy is to recommend the rehabilitation strategy that has the largest positive expected net economic benefits. Thus far, approximately 20 major rehabilitation reports have been

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[2]See for example Moser, et al, 1995 and USACE, 1994.

submitted supporting major rehabilitation spending of about $600 million. Due to budget limitations, not all these projects have received funding. Reports approved so far have been primarily for rehabilitations of hydroelectric and navigation machinery and equipment. One distinguishing aspect of rehabilitation analysis results for hydroelectric projects is the importance of non-reliability related benefits. These stem from the opportunity to "uprate" electric generation capability during a major rehabilitation. The benefit from reducing unreliability in these projects comprises only 5% to 20% of the total, which is never sufficient to cover the major rehabilitation cost. This compares with reliability related benefits of nearly 100% for major rehabilitations of other types of projects. Not all projects studied for major rehabilitation have produced reports supporting major rehabilitation. This implies that a "fix as fail" strategy is the most economically efficient response to unreliable performance in some cases. Additionally, spending to rehabilitate some features or components has been shown not to meet the expected net benefits test.

The Corps major rehabilitation program has successfully applied risk analysis principles to investment decisions about aging hydraulic structures. Fortunately, the Corps has not faced the difficult decisions involving human health and safety as in dam safety. Major rehabilitation primarily is about financial risks where the use of an expected value decision criterion is usually appropriate.

FLOOD DAMAGE REDUCTION

The Corps of Engineers has used a risk analysis approach to flood damage reduction project evaluation for decades. A statistic, expected annual flood damage, is estimated by computing the area under a flood damage-frequency curve. This curve or function is derived by combining a discharge-frequency function, with stage-discharge and stage-damage functions shown in Figure 2. The frequency-damage function provides a concise representation of the risk; likelihoods are from the discharge-frequency function and the adverse consequences are the damages. The Corps has relied only on the expected value statistic to represent the economic performance of any flood damage reduction alternative. Hydrologic and hydraulic engineers and economists have long recognized that this computation ignores large uncertainties in the discharge, stage, and damage. To account for uncertainty in discharge, the Corps adopted an "expected probability" approach following an interagency committee recommendation.[3] (IACWD, 1982) This does not quantify the uncertainty in the discharge and carry it forward. Instead, the expected probability adjustment increases the deterministic discharge for rare flows attempting to account for the sparsity of historical data. Uncertainty in the stage calculations was recognized but not quantified. Hydraulic engineers adopted a risk management strategy of adding freeboard on dams and levees to be assured of passing the uncertainty stage of the design flow. Uncertainty in damage was ignored.

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[3]For a discussion and further references on the debate about the use of expected probability see NRC, 1995.

In 1991 the Corps adopted a more thorough risk analysis approach to the engineering and economic evaluation of all the flood damage reduction projects it plans and builds.[4] There were several reasons for developing and carrying out this methodology. First, often the Corps added a "standard" freeboard to projects without trying to quantify the error in stage. At some locations the standard freeboard effectively provided more protection than claimed. Second, the practice of hydraulic engineering had not progressed with the science. The science had become more statistically oriented and the models for predicting stages more sophisticated than presumed by the simplistic addition of freeboard. Third, freeboard provided added engineering reliability and economic benefits that were frequently not properly accounted for in project performance evaluations. Fourth, single indexes of engineering performance, (e.g., level of protection), and economic performance, (e.g., benefit-cost ratio) convey a false impression of certainty. These single numbers masked a large amount of uncertainty about the performance of projects.

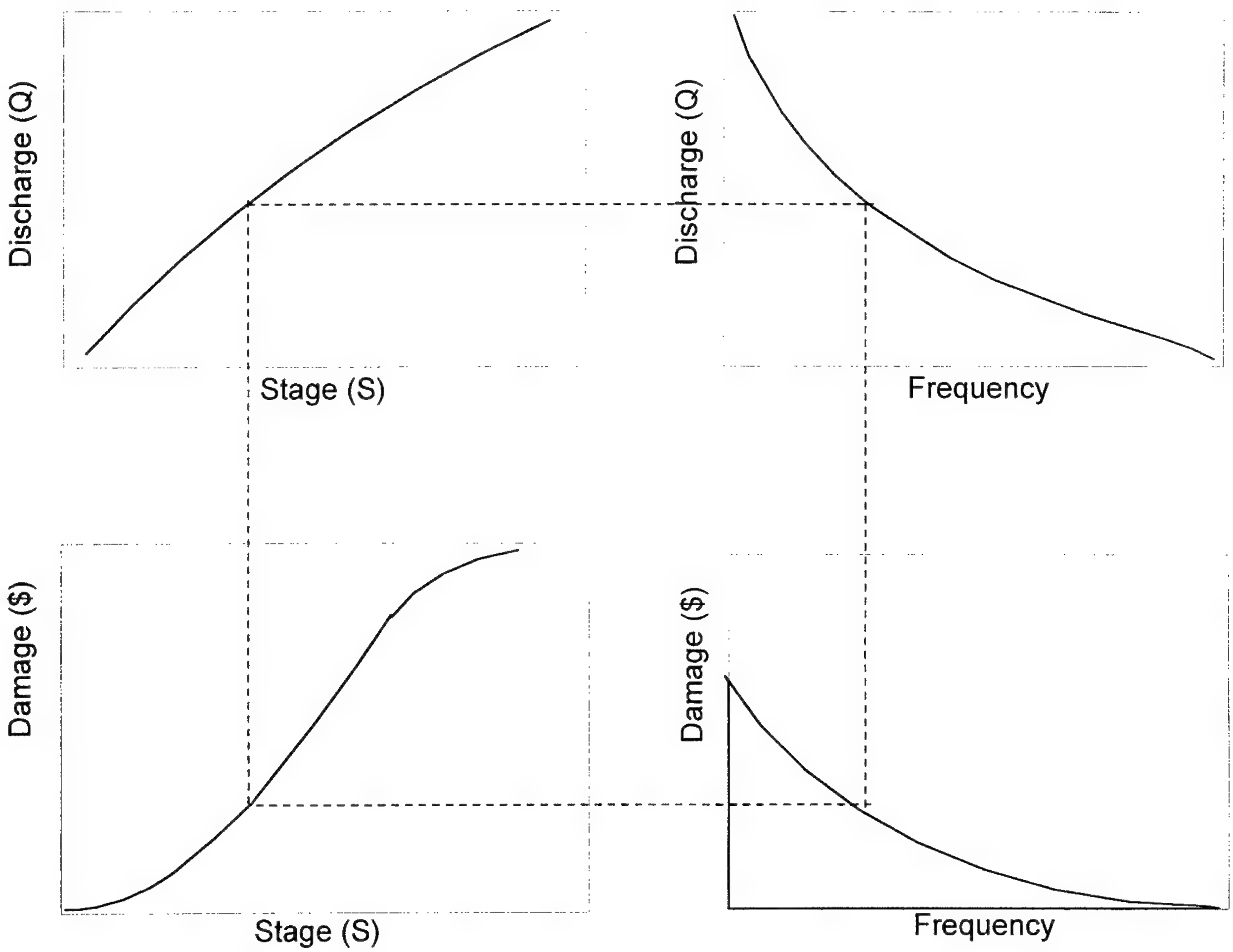

Figure 2: Frequency-Damage Estimation

[4]For current policy and procedures see USACE, 1996 and USACE, 1996b.

Plan	Residual Annual Probability Exceedance	Equivalent Annual Cost
W/O Project	0.250	0.0
20 foot Levee	0.020	300.0
25 foot Levee	0.010	400.0
30 foot Levee	0.001	550.0
Channel	0.025	300.0
Detention Basin	0.030	275.0
Relocation	0.100	475.0

Table 1: Risk-Cost Tradeoff

Current Corps policy requires the use of risk analysis methods for all flood damage reduction projects. The policy emphasizes concentrating on the uncertainty in variables that are key to project recommendation. Key variables enter the analysis by influencing uncertainty in flood discharge, flood stages, and flood damage. By quantifying these uncertainties, the measures of project performance can include a complete statement of risk and uncertainty. Specific uncertainties that must be addressed are discharge associated with exceedance frequency for hydrologic studies, conveyance roughness and cross-section geometry for hydraulic studies, the reliability of existing protective structures, i.e., existing levees, and stage-damage function for economic studies. (USACE, 1996). The basic approach advocated is to identify and quantify the uncertainty in the variables that contribute to prediction of discharge, stage, or economic damage. These uncertainties are then combined using the traditional engineering-economic model for estimating damage-frequency as shown in Figure 2.

The Corps has developed several generations of computer software tools to combine the uncertainties. These all rely on Monte Carlo simulation to derive resultant distributions of damage reduced and to describe engineering reliability. The latest computer software incorporating risk analysis into flood damage reduction project evaluation is described in Burnham, 1996.

The Corps risk analysis approach provides a more thorough description and can provide more understanding about the engineering and economic performance of any flood damage reduction alternative. National economic development (NED) remains the Corps decision rule for project selection. The risk information generated can provide the basis for a deviation from the NED plan to meet a reliability goal or a cost constraint. For instance, Table 1 shows the risk-cost tradeoffs for several flood damage reduction plans. The NED plan might be the 20-foot levee but the local cost sharing partners might find the residual risks unacceptable. They may be willing to pay the additional $100k per year to pay for the construction of the 25-foot levee.

Table 1 shows only one aspect of the information developed from a risk analysis. In fact, care must be taken to avoid invalid comparisons since this table shows only one tradeoff between plans. Other tradeoffs, such as risk versus population exposed, may differ between plans. This can occur if a plan opens land to development by providing protection against the FEMA base flood. Alternatively, exceedance of a plan may have small consequences such as a channel improvement.

The Corps use of risk analysis attempts to provide better information to improve decisions making. As stated in ER 1105-2-101:

> "All project increments comprise different risk management alternatives represented by the tradeoffs among engineering performance, economic performance, and project costs. These increments contain differences in flood damage reduced, in residual risk, and in local and Federal project cost. It is vital that the local customer and local residents understand these tradeoffs in order to fully participate in an informed decision-making process."

SPECIAL RISK ANALYSIS APPLICATIONS

Not all uses of risk analysis by the Corps fall into the categories where formal policy guidance exists. Risk analysis methods have provided the only means of trying to answer specific questions for individual projects Three specific examples provide an indication of the scope of Corps practice.

One application involved estimating the reduction in vessel collision and grounding damages due to widening of the Houston Ship Channel, (Moser, et al, 1995). Reducing these damages is a benefit from the channel improvement beyond the traditional shipping cost savings. The characterization and quantification of the likelihoods and consequences, with uncertainty involved several steps. First, historical casualty rates for the project site were calculated from U.S. Coast Guard records. The year to year variability was also calculated. Second, the distribution of casualty damages by casualty type was estimated from the same records. These were verified and adjusted based on interviews of affected parties from a sample of recent casualties. To quantify the risk reduction from channel modifications, subjective probability assessment elicited the risk reductions from a group of experts including the U.S. Coast Guard, the local pilot associations, and representatives of barge companies. Uncertainties, including uncertainties in the risk reductions, were carried forward to derive a distribution of casualty reduction benefits.

A second application estimated the risk of closure of the Poe Lock, Sault Ste. Marie, Michigan. Of particular interest was the likelihood of an extended lock closure from a vessel related incident. Vessel collision, fire and explosion, and lock gate impact, among other events were considered in this conventional risk analysis application. Weather and human error were also considered as contributing factors. None of the events has ever occurred at the lock. Throughout the world, the occurrence of any of these event is rare. A group of vessel masters, shippers, and lock operators was used to develop event trees mapping the process from initiating events to the terminal event, the length of lock closure, resulting form vessel incidents at the Poe Lock. With these event trees, a structured subjective probability assessment method was used to elicit probabilities of initiating and contributing factors from this same group. Additionally, the length of closure resulting from each terminal event was elicited from the experts. Divergence of options about probabilities and times of closure were carried forward and included in the uncertainty description of the results. Finally, the event trees and the probabilities were used to calculate the probabilities of different closure durations.

A third ongoing application uses risk analysis to evaluate an existing Corps requirement to provide an emergency closure system for hydroelectric unit intake gates that can stop the flow of water within ten minutes of activation. The requirement is intended to prevent extensive damage to a generating unit and possibly the powerhouse. At some hydropower projects in the Pacific Northwest, emergency closure times are longer due to alterations to improve water flow to divert juvenile fish. The study will help decide if costly modifications to achieve the closure time goal are worth the investment. Extensive event trees and fault trees were developed tracing initiating events to terminal events, possible damaging events. Probabilities of time to closure for different damaging events have been developed for different physical configurations of powerplants, representative of different Corps projects. Damages, including the cost of replacing lost power during repairs, have been estimated for different damaging events and times to closure. A survey of Corps and non-Corps hydropower projects developed estimates of historical frequencies to calculate the probabilities of the terminal events. These were then supplemented using subjective probability assessment by an expert panel representing machinery manufacturers, power producers, experts in installation and repairs, private powerhouse insurers, powerhouse operators and powerplant designers. A Bayesian analysis was used to combine the estimated historical frequencies with the expert judgments. Combining the probabilities of duration of damaging events with damages as a function of durations, expected annual damages were estimated for each of the powerhouse configurations. The preliminary results suggest that modifications in emergency gates can be cost effective for some sizes of powerhouses and some powerhouse configurations.

EXPANDED USE OF RISK ANALYSIS

The Corps of Engineers is pursuing expanded application of risk analysis methods. Coastal protection projects are similar to flood damage reduction projects in many respects, offering a natural opportunity to apply risk analysis. An important distinction, however, is the cumulative impacts of storms on a coastline. To address this issue, a life-cycle approach, using Monte Carlo simulation to combine uncertainties is proposed. Deep draft navigation investments display many engineering and economic uncertainties that can influence the identification of economically efficient investments. The Corps is developing approaches, models, and evaluations that account for uncertainty in forecasts of commodity flows and vessel fleets, dredging costs, and dredged volumes. Risk analysis applications to shallow draft navigation investments are also under development.

Operating and maintaining existing projects now accounts for over half the Corps civil works budget. To more efficiently allocate scare resources, risk analysis approaches are being considered to help balance project reliability and economic value against operations and maintenance costs.

Expanding the use of risk analysis has its critics within the Corps. Partly this stems from the added study costs as practitioners learn new methods and ways of thinking. As learning grows and as new models are developed, meeting risk analysis requirements will be less costly. By quantifying uncertainties and explicity including them in the evaluation, some studies may be completed without the high cost of collecting some primary data, resulting in lower study costs. These benefits are speculative at this time, however. Criticism of adopting risk analysis approaches also arises from

skepticism about the "value added" of the analysis. Critics argue that if the method does not change the answer, the Corps should not go to the expense of conducting the analysis. Sometimes, the answer is different, but not always in the direction of less costly projects. Large uncertainties in flood flows can lead to projects larger than that proposed in a deterministic analysis. An additional value added is a better understanding of how a project can perform. This can be very valuable in helping cost-sharing partners and potential beneficiaries make better decisions. A final criticism of risk analysis is the difficultly of communicating information about project performance in terms of means, variances, and probabilities. These critics argue that the lay audience will not understand and are not interested in uncertainties and risk. This is a frequent and, partially, valid criticism of risk analysis. Decision makers and the public need to be enlightened, not confused. Techniques for communicating risk information are improving and the public is becoming more accustomed to information couched in risk terms. There is a need to spend more effort adopting terminology and displays of risk analysis results that recognize the sophistication of the audience.

CONCLUSION

The Corps of Engineers has used risk analysis techniques and ideas for many years. It has only been in the last decade, however, that risk analysis methods have been explicitly integrated into decision making. This integration has provided the risk-cost and risk-net benefit tradeoffs, and distributions of net benefits. These provide additional information for decision making and a better understanding of how a water resource investment works. Given this information, better decisions can be made. By explicitly examining risk-cost tradeoffs, the Corps is reconsidering the value of requiring some standard assumptions and criteria in all instances. Allowing some flexibility can reduce project costs will only small sacrifice in project performance.

Note: All opinions expressed are those of the author and do not necessarily represent the policy of the U.S. Army Corps of Engineers.

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RISK BASED ANALYSIS IN FLOOD DAMAGE REDUCTION STUDIES

by

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INTRODUCTION

The concepts of Risk Based Analysis (RBA) are not new. Evaluation of risk and accommodation of uncertainty have been important considerations in the development of flood damage reduction projects since the Corps became involved in the 1920's. The concepts of risk and risk reduction form the very foundation of the Corps flood damage reduction program. Furthermore, the formal consideration of risk in project formulation studies has been required by the Planning Guidance Notebook (ER 1105-2-100) since it was first published in the early 1980's.

Until recently there was no systematic procedure to account for risk. The development and use of RBA in flood damage reduction project formulation studies has permitted more informed decisions because much more detailed information on project economics and project performance is now available to the decision maker. For the first time, we have a method that enables us to explicitly and analytically integrate risk and data uncertainty directly into the analysis. In spite of the power of the RBA methodology, it should still be thought of as simply one tool in the toolbox. In the formulation and design of a flood damage reduction project, RBA is only one part of the total study effort.

Finally, with the trend in the Federal government toward use RBA methods as the bases for investment decisions, the Office of Management and Budget (OMB) has encouraged and supported the Corps in the development of this technology. Thus, the continued use and improvement of RBA is critical to the Corps in maintaining a viable flood damage reduction program.

HISTORY OF RBA IN THE CORPS

Corps involvement with RBA began in the early 1980's with an attempt to develop a RBA procedure to evaluate hydrologic deficiencies at Corps reservoir projects, as part of its Dam Safety Assurance Program. These efforts, while unsuccessful in establishing a comprehensive RBA method, did result in a quasi-risk based method of evaluation, known as incremental hazard analysis, that was published in a 1985 Corps Policy Letter. Today the same guidance is contained in ER 1110-2-1155. This method of analysis is presently used by all Federal dam building agencies to evaluate hydrologic deficiencies.

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During the early 1990's, a RBA method was developed to allow uniform evaluation and prioritization of projects proposed for remedial work under the Corps Major Rehabilitation Program. Implementation guidance was published in 1993.

In the area of flood damage reduction, development of the current RBA method began with a workshop on riverine levee freeboard, held in Minneapolis, MN, in August 1991. At this workshop the basic approach to RBA for flood damage reduction project formulation was presented and discussed. Following the workshop, efforts to fully develop the method were undertaken and the first Corps guidance on application was published as EC 1105-2-205 in 1993. During 1993 and 1994 a series of five workshops were conducted throughout the country to introduce Corps field offices to the emerging technology. At the same time, coordination of the RBA method was undertaken with the Federal Emergency Management Agency (FEMA) and the Association of State Floodplain Managers (ASFPM), both of whom expressed some reservations relative to the application of RBA, particularly with respect to Corps levee certification. In order to provide for an independent technical review, the National Research Council (NRC), as part of a Congressionally mandated review of the American River project, was asked by the Corps to evaluate the RBA procedure used in the formulation studies for this project. The final NRC report raised some technical issues, but in general supported the RBA approach. The ASFPM still had some concerns with widespread use of RBA and as a result of these concerns, Congress directed the Corps, in WRDA '96, to again seek an independent review by the NRC, that would be more general in scope than the previous review that addressed only the American River application. This review, which the Corps expects will result in a positive conclusion, will begin in 1998 and take about two years to complete. In the meantime the Corps remains committed to RBA and will continue to use RBA in flood damage reduction studies. Current policy guidance on application of RBA to flood damage reduction studies is contained in ER 1105-2-101, while engineering guidance is contained in EM 1110-2-1619.

Ongoing efforts in the development of RBA procedures for additional applications are focused on navigation, both deep and shallow draft, and coastal engineering.

OVERVIEW OF RBA FOR FLOOD DAMAGE REDUCTION STUDIES

The development of the current RBA methodology has been a true Corps-wide effort. It has been interdisciplinary (engineering and economics), inter-laboratory (HEC, IWR and WES) and has had the benefit of field office application. In addition, RBA has been extensively coordinated with other Federal agencies and non-governmental organizations.

Formulation and Design Objectives. Flood damage reduction projects are formulated to provide safe, efficient and effective protection to lives and properties in flood prone areas. Projects are formulated by analyzing flood plain damage potential, and damage prevention performance and cost for a range of project sizes and configurations. The plan selected is based on maximizing net economic benefits consistent with acceptable risk and functional performance.

The engineering challenge is to balance risk of design exceedance with flood damage prevented, uncertainty of flood levels with design accommodations, and provide for safe and predictable performance. The task is made difficult because economics dictate that less than complete protection be accepted, risk of capacity exceedance is real and must be planned for because it may occur within the life of the project, and uncertainty in flood levels exists because of imperfect knowledge.

Uncertainty in the Analysis. Planning flood damage reduction projects requires information on discharge/frequency, stage/discharge, and stage/damage relationships at points along the stream where protection is to be provided. Such information is obtained from observed and measured data, or is estimated by various synthetic procedures and modeling techniques. The information is frequently based on short records and small sample sizes, and subject to measurement errors and inherent limitations and assumptions associated with the analytical techniques employed. These estimated values are, to various degrees, imprecise or inaccurate and thus induce uncertainty in key variables and decision making parameters.

Risk-Based Analysis Approach (ref. 1). RBA is a method of performing studies in which uncertainty in technical data is explicitly taken into account. With such analyses, trade-offs between alternatives, risk, and consequences are made highly visible and quantified. The overall effect of risk and uncertainty on project design and economic viability can be examined and conscious decisions made reflecting an explicit tradeoff between risk and costs.

The RBA approach has many similarities with traditional practice in that the basic data are the same and best estimates are made of discharge/frequency curves, stage/discharge curves (water surface profiles), and stage/damage relationships. The difference between the traditional approach and the risk-based approach is that uncertainty in technical data is quantified and explicitly included in evaluating project performance and benefits. Using RBA, performance can be stated in terms of the probability of achieving stated goals. Also, surrogates in the form of adjustments or additions to design features (e.g. freeboard on levees to account for hydraulic uncertainties) to specifically accommodate uncertainty are not necessary.

RBA quantifies the uncertainty in discharge/frequency, stage/discharge, and stage/damage relationships and explicitly incorporates this information into economic and performance analyses of alternatives. The process requires a statistical sampling analysis method to compute the expected value of damage and damage reduced, while explicitly accounting for uncertainty.

The method used to develop the discharge/frequency relationships depends on data availability. For gaged locations and where an analytical determination is appropriate, uncertainties for discrete probabilities are represented by the non-central t distribution (ref. 2). For ungaged locations, the discharge/frequency function may be adopted from applying a variety of approaches (ref. 3). When justified, curve fit statistics for the adopted function are computed. An equivalent record length is assigned based on the analysis and judgements about the quality of information used in adopting the function. Regulated (e.g. by a flood control dam) discharge/frequency, stage/frequency and other non-analytical probability functions require

different methods. An approach referred to as "order statistics" (ref. 3) is applied to develop the probability function and associated uncertainty for these situations.

Stage/discharge functions are developed for index locations from measured data at gages or from computed water surface profiles. For gaged data, uncertainty is calculated from the deviations of observations from the best fit rating curve. Computed profiles are required for ungaged locations and for proposed project conditions that are modified from that of historic observations. Where sufficient historic data exists, water surface profile uncertainty is estimated based on the quality of the computation model calibration to the historic data. Where data are scant, or the hydraulics of flow complex, such as for high velocity flow, debris and ice jams, and flow bulked by entrained sediments, special analysis methods are needed. One approach is to perform sensitivity analysis of reasonable upper and lower bound profiles and use the results to estimate the range of the uncertainty in stage.

Stage/damage functions are derived from inventory information about structures, structure content and other damageable property located in the flood plain. The functions are constructed at damage reach index locations where discharge/frequency and stage/discharge functions are also derived. Presently, separate uncertainty distributions for structure elevation, structure value, and content values are specified and used in a Monte Carlo analysis to develop the aggregated structure stage/damage function and associated uncertainty. The uncertainty is represented as a standard deviation of error at each stage coordinate used for defining the aggregated function at the index location.

In the development of the best estimates and the error distributions for the three primary parameters discussed above, a "common sense approach" should be taken. That is to say, most of the study effort should be devoted to the parameter (or parameters) that will most affect the final recommendation. For example, the frequency curve will generally have the largest impact on the study results, but, if the study area has a broad, flat floodplain, a relatively small increase in water surface elevation can have a major effect on both discharge and damage estimates, and thus should be studied in greater detail. The total amount of effort to needed to adequately define these parameters should be based on the type of study (e.g. recon, feasibility, etc.), and the size and complexity of the project.

The basic steps to carry out the RBA are:

a. Develop best estimates of discharge/frequency curves, water surface profiles (stage/discharge ratings), and stage/damage relationships for the without project conditions.

b. Develop statistical descriptions of uncertainty for each of the above relationships.

c. Nominate alternative project capacities; compute costs and flood damage prevented; array results and select a plan according to appropriate economic criteria.

Parameter estimates for the with project conditions used, in step c above, are developed by modifying the appropriate without project parameters. For a reservoir or diversion project, the frequency curve would be modified to reflect the effects of storage or diversion on flows in the damage reaches. For a channel or levee project the rating curve in the damage reach would be

modified to reflect greater channel capacity. For a non-structural project the depth/damage curve would be modified.

The above steps are repeated as needed for each alternate measure evaluation, or combinations of measures to enable comparison of project alternatives. Step c brings together all the elements to determine the selected project capacity. To correctly incorporate uncertainty in the several elements, they must be allowed to interact with one another. For example, the possibility of error for higher flows (or lower flows) of a specific probability flood must be allowed to couple with the full range of possible stage and damage errors. Because of the nature and complexity of the error distributions, the interaction cannot be uniquely accomplished analytically. An alternative approach is to use Monte Carlo simulation. In this approach, the basic relationships and error distributions are sampled by exhaustive trial to allow the interaction to take place. For a given size or type of project, various combinations of the primary parameters are evaluated and for each interaction success or failure is established. Other project sizes and/or types are evaluated, and a matrix describing economic outputs and performance for each is produced. The matrix forms the basis for initial project selection.

The results of the analyses are probability distributions of the various parameters (flow, stage, and residual damage) as a function of project capacity. The expected cost and benefit for each alternative are computed and the most economical project capacity selected according the appropriate criteria. Tabulations of the likelihood of project capacity exceedance for flood events are produced that enable characterization of risk exceedance and performance. The RBA method quantifies the performance of project design. This performance is reported as the protection for a target percent chance exceedance flood with a specified annual non exceedance probability. For example, the proposed project is expected to provide protection against the one-half percent (0.5%) chance exceedance flood, should it occur, with a ninety percent (90%) chance of non exceedance. This performance may also be described in terms of the percent chance of controlling a specific historic flood to non-damaging levels.

The first applications of RBA were conducted using a spread sheet program to perform the evaluation. Recently HEC has developed a more user friendly flood damage assessment computer program that has greatly facilitated the application of the RBA procedure.

Summary of RBA. Imperfect knowledge of the "true" nature of the hydrology and hydraulics in an area creates uncertainty in project designs and in the estimate of their expected performance. Additionally, uncertainties in expected damage with and without the project can greatly influence the selection of an alternative plan for design. RBA procedures provide an approach to explicitly quantify the uncertainties associated with discharge/frequency, stage/discharge and stage/damage relationships that are required in the formulation of flood damage reduction projects. The method uses the same basic data as that used in traditional practice, but has the distinct advantage of providing considerable information regarding expected project performance for a broad range of hydrologic conditions. Goals and objectives of project studies are enhanced due to the ability to consider a much wider range of project alternatives.

Initial Applications of RBA. RBA studies conducted to date have been very promising (ref. 4) and feedback from field offices has been positive. In several instances the basic framework has been modified to account for unique circumstances such as the effects of upstream levee breaks and the impact of tidal fluctuations on frequency relationships.

Development of Additional Capabilities. Current research and development efforts are aimed at developing improved geotechnical capabilities and new methods for evaluation of project cost uncertainties for inclusion in the RBA procedure.

OTHER RISK RELATED CONSIDERATIONS

Risk Based Analysis is only one component of a much larger process in a flood damage reduction study. While RBA provides the engineer with a wealth of information that was not previously available, it is not a substitute for good engineering practice, nor is it intended to be. The RBA discussed in this paper is used to formulate the type and size of the optimal structural (or non-structural) plan that will meet the study objectives. Corps policy requires that this plan be identified in every flood damage reduction study it conducts. This plan, referred to as the National Economic Development Plan (NED), is the one that maximizes the net economic benefits of all the alternatives evaluated. It may or may not be the recommended plan based on additional considerations.

The first step in a flood damage reduction study is to conduct the RBA. The RBA identifies the NED Plan and provides a starting point for the design process. As discussed previously, output from the RBA includes data on stage exceedence probabilities and expected project performance at index locations along the stream.

A residual risk analysis for the NED Plan is next performed to determine the consequences of a design exceedence. We know that for a flood damage reduction project, the question is not **IF** the design will be exceeded, but what are the impacts **WHEN** that design is exceeded, in terms of both economics and the threat to human life! If the project induced and/or residual risk is unacceptable, and a design to reduce the risk cannot be developed, other alternatives must be further analyzed. Either a larger project, that will assure sufficient time for evacuation, or a different type of project, with less residual risk, should be studied to reduce the threat to life and property.

When the type and size of the project have been selected, we are ready to begin the detailed design. To attain the confidence that the outputs envisioned in the formulation of the selected project will be realized, specific design requirements are developed. For a levee, increments of height to provide for settlement and consolidation, allow for construction tolerances, and permit the building of a road along the crown for maintenance and access during flood fights are calculated. For a channel project, superelevation, if required to contain the design water surface profile, is determined. For a reservoir, allowances to accommodate the Inflow Design Flood without endangering the structure and to account for wind and wave action are estimated. A similar thought process is also used for upstream diversion projects. These

specific requirements must be included in the design.

The design must also include measures to minimize the adverse impacts of a design exceedence. For levees, the final grade is set so that initial overtopping will occur at the least hazardous location along the line of protection. This location is usually at the downstream end of the levee, so the protected area will fill in a gradual manner. This same approach is taken in the final design of channel projects. For reservoirs, the Water Control Plan is developed so that as the point of design exceedence is approached, there is a gradual increase in outflow from the project to provide time to initiate emergency measures downstream. Upstream diversions are also configured (or operated) to allow a gradual increase in flow during a design exceedence. These design efforts notwithstanding, it is normal practice to include a flood warning system in the final plan as a last measure for risk reduction.

Design of a flood damage reduction project places a special responsibility on the design engineer because of the potentially catastrophic consequences of a design exceedence. Of the types of structural projects usually considered in a flood damage reduction study, a levee is by far the most dangerous due to the severe consequences that may result from overtopping. If a levee cannot be designed to assure gradual filling of the protected area when the design is exceeded, then it simply should not be built. Reservoirs, channels and upstream diversions are better structural choices than levees from a hazard perspective. They provide some measure of protection even after their design is exceeded, and, they are better suited to minimize the adverse impacts of a design exceedence because they can be designed and/or operated to effect a gradual increase in flows and inundation in the protected areas.

CONCLUSION

The Corps is committed to the use of RBA in all flood damage reduction studies. RBA has greatly improved our ability to formulate quality projects through the production of additional economic and performance data not previously available. As we continue to expand our capabilities by the addition of procedures to address geotechnical and cost uncertainties, RBA will become an even more powerful tool. When RBA is coupled with sound engineering practice, the best project from a public safety and hazard reduction standpoint results.

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RISK BASED ANALYSIS
FOR
THE AMERICAN RIVER WATERSHED PROJECT

by
Michael K Deering [1]

HISTORY

Sacramento was established in the 1840's at the confluence of the Sacramento and American Rivers. Flooding was common and regular as the community grew. Over the years, a complex system of levees, bypasses and dams and reservoirs were constructed to help reduce the damage caused by flooding. Still, the city is at great risk today. There are nearly 400,000 people and $37 billion of damageable property protected by 15 to 20 foot high levees. Many of these levees were built over 50 years ago. In February 1986, the "storm of record" occurred in the American River Basin and revealed the true nature of the flood control capabilities of the system. The system was taxed for nearly seven days with channel and levee capacity flows. As a result of this flood and subsequent hydrologic studies, the 1986 event showed that Sacramento has a modest level of protection at best - substantially below the 100-year threshold for the national flood insurance program.

SYSTEM

Sacramento is bound on the west by the Sacramento River and bisected by the American River which flows east from the Sierra Nevada Mountains. The American River watershed covers approximately 2,100 square miles and includes portions of Placer, El Dorado and Sacramento Counties. The basin is partially regulated on the North Fork of the American River by several small reservoirs and on the main stem by Folsom Dam. The Folsom Dam and Reservoir, located about 29 miles upstream of Sacramento, are key features in the flood control system (See Figure 1). The levees along the American River downstream of Folsom Dam are likely to fail at various locations when sustained flows reach between 130,000 cfs and 160,000 cfs. The risk or probability of failure, given a 100-year event, is approximately 0.60.

ALTERNATIVES

The goal of the American River Watershed Project is to significantly increase the level of flood protection for Sacramento. The local sponsor indicates that a flood control alternative implemented in the Sacramento area should provide nothing less than a 200-year level of protection. Seventeen individual measures were identified as possible configurations for project alternatives. These measures were arranged to compile an array of eight possible flood control alternatives(See Table 1). The nominated alternatives for evaluation fall into three basic categories.

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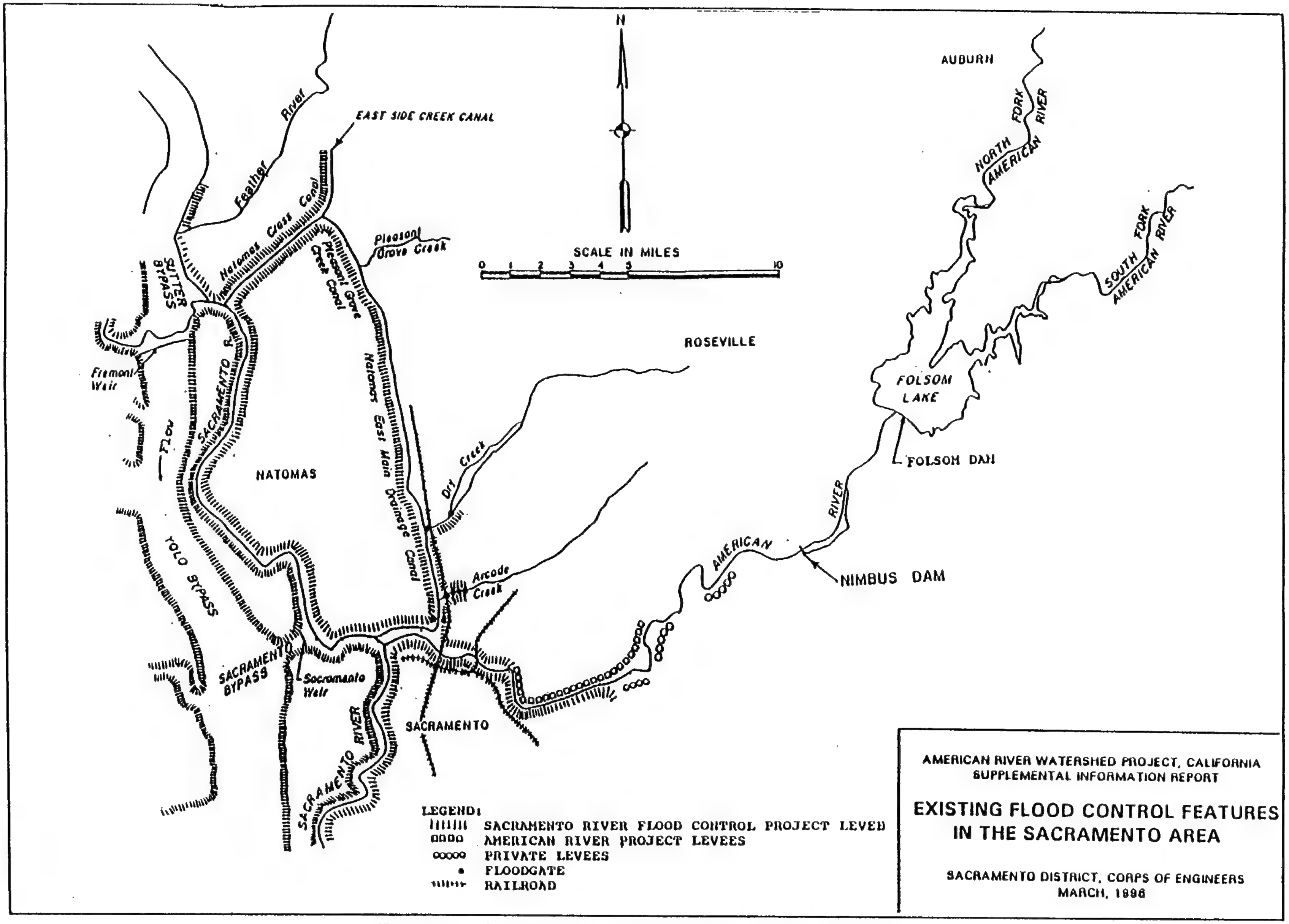


Figure 1 - Sacramento Area Flood Control Features

The categories include a flood detention dam on the North Fork of the American River just upstream of Folsom Dam, operational and structural modification to Folsom Dam, larger flood control releases from Folsom Dam requiring modification to the downstream flood control system, and the use of existing upstream storage. The final candidate plans that represent these three categories are the Folsom Modification Plan, the Folsom Stepped Release Plan and the Detention Dam Plan.

RISK-BASED ANALYSIS

The Risk-Based Analysis (RBA) procedures developed by the U.S. Army Corps of Engineers' Hydrologic Engineering Center (HEC), Davis, Ca., were used to evaluate the economic benefits and the hydrologic performance of each alternative. In addition to the standard methods and tools, HEC customized software to accommodate the analysis of a regulated system, and index points

Table 1 - Summary of Initial Alternatives

Alternatives	Primary Alternative Features
Minimum Impact [1] Folsom Modification Plan	Increase flood control space, surcharge space, modify Folsom outlets, minor change to objective release and downstream channel capacity (115,000 cfs).
Minimum Objective Release	Increase flood control space, surcharge space, modify Folsom outlets, minor change to objective release and downstream channel capacity (130,000 cfs).
Moderate Objective Release	Increase flood control space, surcharge space, modify Folsom outlets, moderate change to objective release and downstream channel capacity (145,000 cfs).
Maximum Objective Release	Increase flood control space, surcharge space, modify Folsom outlets, major change to objective release and downstream channel capacity (180,000 cfs).
Stepped Release [1]	Increase surcharge control space, surcharge space, modify Folsom outlets,major change to objective release and downstream channel capacity (145-180,000 cfs).
200-Year Storage	Construct a 380,000 ac-ft flood detention dam upstream from Folsom Reservoir.
Equivalent Storage	Construct a 545,000 ac-ft flood detention dam upstream from Folsom Reservoir.
Detention Dam Plan [1]	Construct a 894,000 ac-ft flood detention dam upstream from Folsom Reservoir.

[1] Final candidate plans

where the use of stage-frequency data is more appropriate than discharge-frequency and stage-discharge data. Nine index points were used to evaluate existing and project conditions over the study area (See Figure 2). Two of the index points were used to determine expected annual damage (EAD) and all nine were used to evaluate the reliability of levee performance (Reliability). Figure 3 displays the performance matrix used to present the RBA results for the base condition and for each alternative. By index point, each matrix presents the Reliability afforded by a given levee for the base condition (R_x), as well as the Reliability for that alternative (R_b). Additionally, the matrix presents the percent chance of non-exceedance expressed as True Exceedance (TE) for the base and alternative conditions. For alternatives that increase downstream flows, incremental decreases in

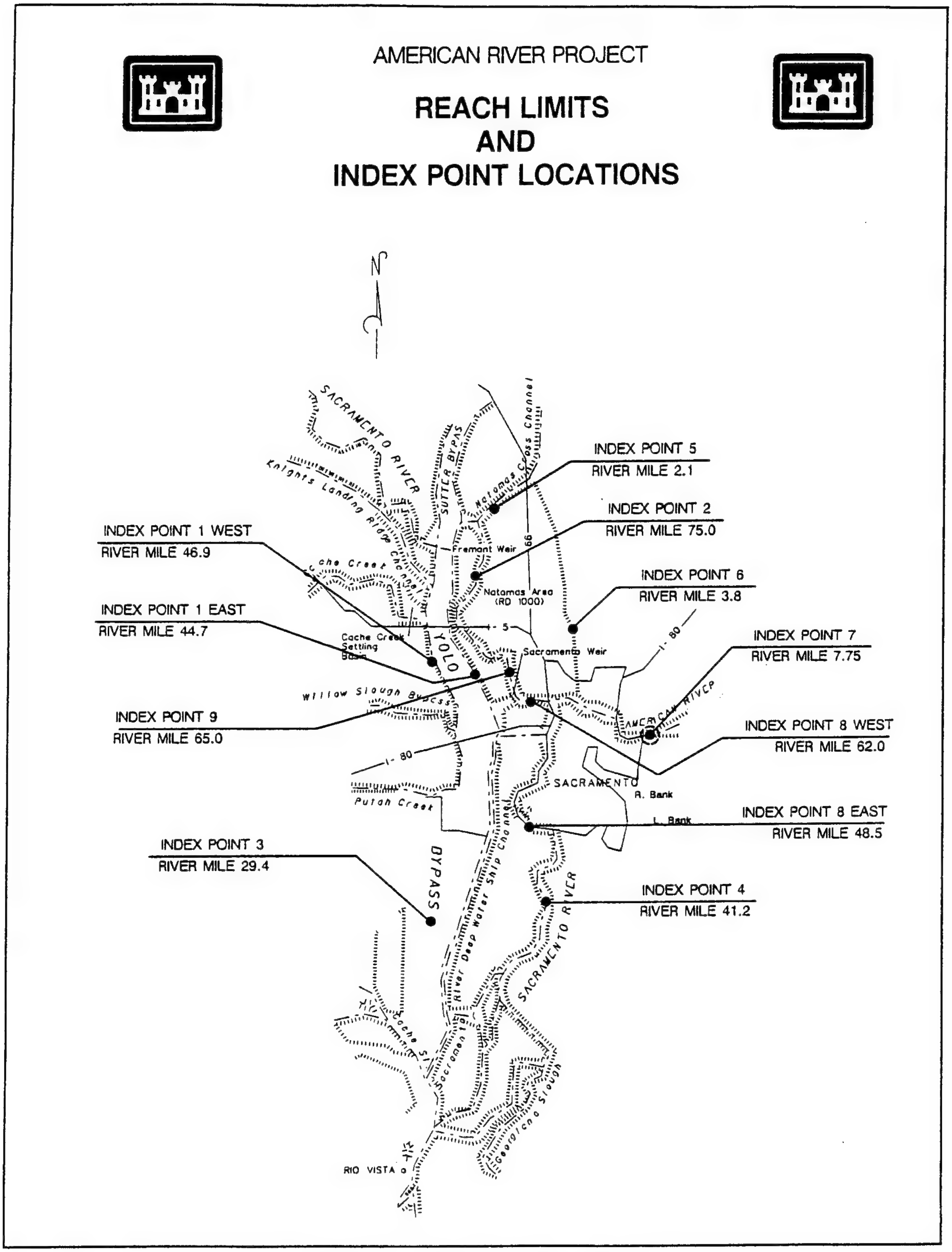
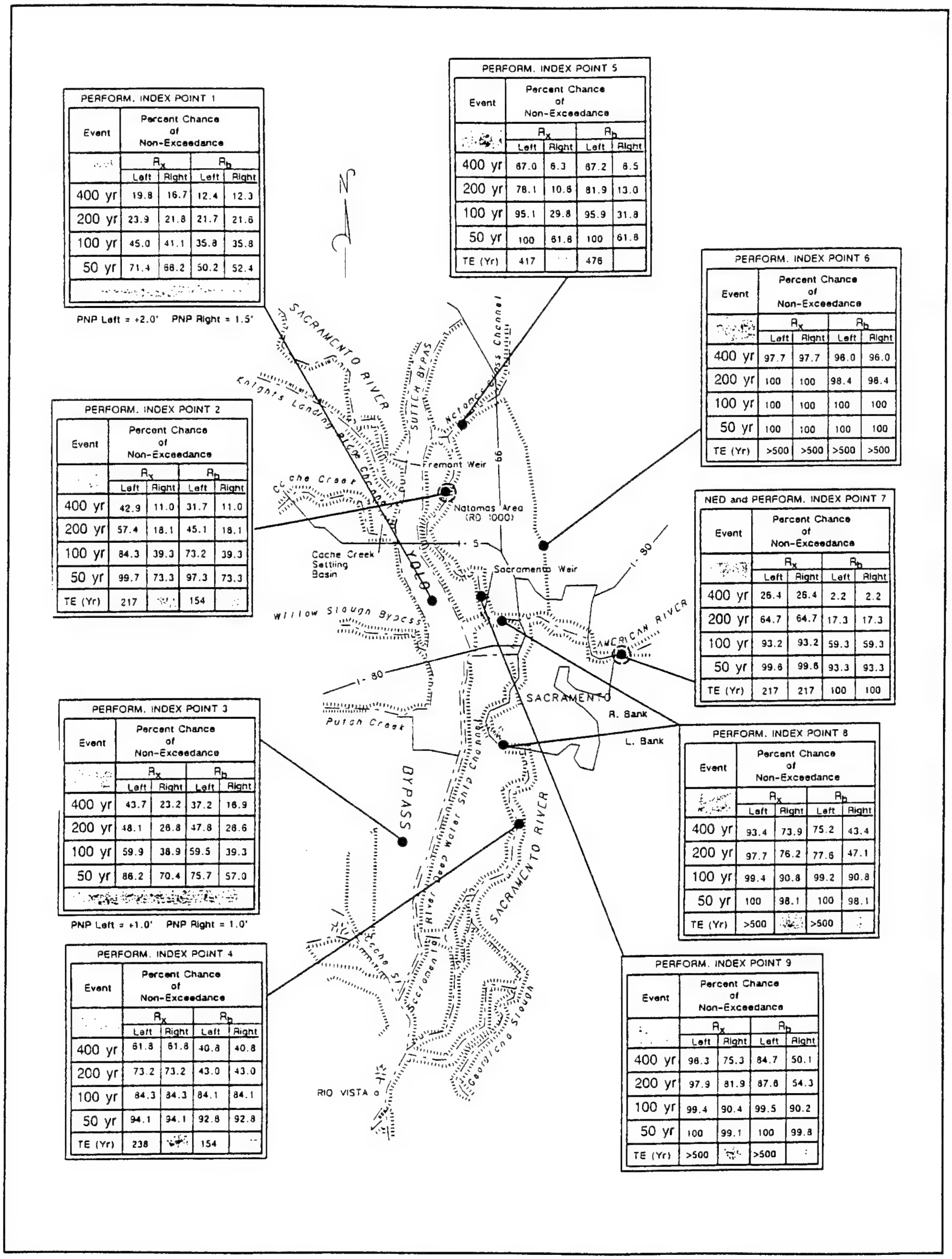


Figure 2 - Index Point Locations



PERFORM. INDEX POINT 1 (Percent Chance of Non-Exceedance)

Event	R_x Left	R_x Right	R_b Left	R_b Right
400 yr	19.8	16.7	12.4	12.3
200 yr	23.9	21.8	21.7	21.6
100 yr	45.0	41.1	35.8	35.8
50 yr	71.4	68.2	50.2	52.4

PNP Left = +2.0' PNP Right = 1.5'

PERFORM. INDEX POINT 2 (Percent Chance of Non-Exceedance)

Event	R_x Left	R_x Right	R_b Left	R_b Right
400 yr	42.9	11.0	31.7	11.0
200 yr	57.4	18.1	45.1	18.1
100 yr	84.3	39.3	73.2	39.3
50 yr	99.7	73.3	97.3	73.3
TE (Yr)	217		154	

PERFORM. INDEX POINT 3 (Percent Chance of Non-Exceedance)

Event	R_x Left	R_x Right	R_b Left	R_b Right
400 yr	43.7	23.2	37.2	16.9
200 yr	48.1	28.8	47.8	28.6
100 yr	59.9	38.9	59.5	39.3
50 yr	86.2	70.4	75.7	57.0

PNP Left = +1.0' PNP Right = 1.0'

PERFORM. INDEX POINT 4 (Percent Chance of Non-Exceedance)

Event	R_x Left	R_x Right	R_b Left	R_b Right
400 yr	81.8	81.8	40.8	40.8
200 yr	73.2	73.2	43.0	43.0
100 yr	84.3	84.3	84.1	84.1
50 yr	94.1	94.1	92.8	92.8
TE (Yr)	238		154	

PERFORM. INDEX POINT 5 (Percent Chance of Non-Exceedance)

Event	R_x Left	R_x Right	R_b Left	R_b Right
400 yr	67.0	6.3	67.2	6.5
200 yr	78.1	10.6	81.9	13.0
100 yr	95.1	29.8	95.9	31.8
50 yr	100	61.8	100	61.8
TE (Yr)	417		476	

PERFORM. INDEX POINT 6 (Percent Chance of Non-Exceedance)

Event	R_x Left	R_x Right	R_b Left	R_b Right
400 yr	97.7	97.7	96.0	96.0
200 yr	100	100	98.4	98.4
100 yr	100	100	100	100
50 yr	100	100	100	100
TE (Yr)	>500	>500	>500	>500

NED and PERFORM. INDEX POINT 7 (Percent Chance of Non-Exceedance)

Event	R_x Left	R_x Right	R_b Left	R_b Right
400 yr	26.4	26.4	2.2	2.2
200 yr	64.7	64.7	17.3	17.3
100 yr	93.2	93.2	59.3	59.3
50 yr	99.6	99.6	93.3	93.3
TE (Yr)	217	217	100	100

PERFORM. INDEX POINT 8 (Percent Chance of Non-Exceedance)

Event	R_x Left	R_x Right	R_b Left	R_b Right
400 yr	93.4	73.9	75.2	43.4
200 yr	97.7	76.2	77.6	47.1
100 yr	99.4	90.8	99.2	90.8
50 yr	100	98.1	100	98.1
TE (Yr)	>500		>500	

PERFORM. INDEX POINT 9 (Percent Chance of Non-Exceedance)

Event	R_x Left	R_x Right	R_b Left	R_b Right
400 yr	98.3	75.3	84.7	50.1
200 yr	97.9	81.9	87.8	54.3
100 yr	99.4	90.4	99.5	90.2
50 yr	100	99.1	100	99.8
TE (Yr)	>500		>500	

Figure 3 - Risk Based Analysis Performance Matrices

the Reliability and True Exceedance were used to determine hydraulic mitigation requirements for that alternative. Geotechnical characteristics of the existing levees and proposed levee enhancements were evaluated using a combination of historic system performance, field testing and stability analysis. The economic evaluations were performed at two index points, one for the Natomas basin and one for the greater Sacramento area. The economic analysis included the generation of the stage-damage function by using Structural Inventory for Damage Analysis (SID) computer program.

HYDROLOGIC ANALYSES

General. The HEC Flood Hydrograph Package HEC-1 model and, Interagency Advisory Committee on Water Data, "Guidance for Determining Flood Flow Frequency, Bulletin 17B," USGS were used to develop discharge-frequency relationships. The American River system is regulated via several small reservoirs in the upstream watershed and by Folsom Dam and Reservoir on the mainstem. Reservoir routing to determine the inflow/outflow characteristics of the storage components were performed using volume balance spreadsheet incorporating spillway and outlet ratings and operational criteria. The HEC-2 model was used to develop stage-discharge data, and the UNET (One-Dimensional Unsteady Flow Through a Full Network of Open Channels) model was used to develop stage-frequency data and to route outflow hydrographs throughout the system. Figure 4 presents a schematic of the hydrologic analysis, including the error distributions for each function.

Discharge-Frequency Functions. In 1961, a statistical analysis was performed to establish the frequency of occurrence for various flows in the American River at the Fair Oaks gage downstream from Folsom Dam. However, because the 1986 flood and five of the ten largest flows in the basin for the 82 years of record have occurred since 1961, and seven of the 10 largest events have occurred since 1951, a new flow-frequency analysis was conducted. A subsequent analysis was performed to include the last eight years of record. The re-analysis included establishing the adjusted unregulated flow removing the routing effects of the upstream storage including Folsom Reservoir. The guidelines set out in Bulletin 17B were used to cast the data into a log Pearson Type III discharge-frequency distribution.

Discharge-Frequency Uncertainty. Appendix 9 of Bulletin 17B, was used to quantify uncertainty in the unregulated Folsom Reservoir inflow discharge-frequency function. The period of record used to develop the confidence limits and subsequent uncertainty about the discharge-frequency function was 90 years.

Reservoir Routing. The lower American River is a highly regulated system with Folsom and Nimbus Dams located immediately upstream. Flows and stages in the river are controlled by releases from Folsom Dam. Therefore, in analyzing flood control alternatives for the lower American River, reservoir routing is required. Consequently, EAD computation via simulation must sample Folsom outflow, use stage-discharge functions that represent system performance with the levees in place, and employ error functions representative of these conditions. An inflow-outflow function was developed by repeatedly computing, with a spreadsheet, outflow peaks for given inflow peaks. Reservoir routing to determine the inflow-outflow characteristics of the storage components was

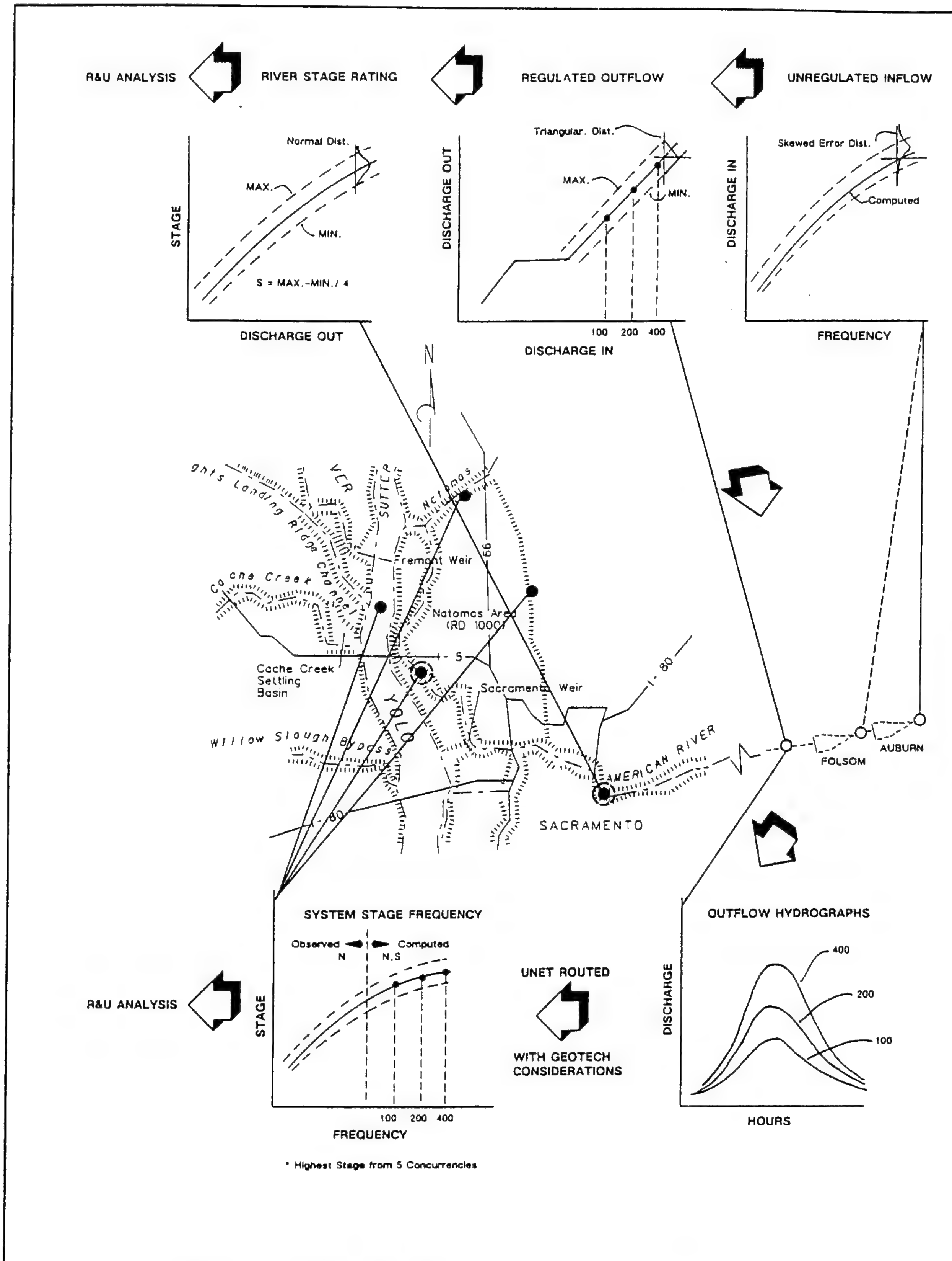


Figure 4 - Schematic of Hydrologic Analysis Components

performed using a volume balance spreadsheet incorporating spillway and outlet ratings and operational criteria. Table 2 summarizes the operational criteria used to perform the base routing and to develop the base and alternative inflow-outflow functions. Figure 5 presents an example of the structure of such a function and is presented in the figure as the "most likely case."

Reservoir Routing Uncertainty. There are uncertainties in the operation of Folsom and the performance of the new detention facility. Itemizing all possible parameters that may impact the outflow was the first step in establishing an uncertainty distribution about the inflow-outflow function. The list included items such as variances in the spillway gates operations, hydropower penstocks operations, river outlet cavitation requiring modification to releases, insufficient personnel to make matching changes at Nimbus and Folsom Dams, political pressure to change operations, inaccurate inflow data, flood event waves varying from the expected, the amount of the available space in Folsom Reservoir, etc. For most of these items it was difficult to quantify the uncertainty they would have on the operation. However, it was determined that sets of conditions could be identified to describe the most likely "best" and most likely "worst" set of conditions that could

Table 2
Current Operation Criteria Used for Base Reservoir Routing

CURRENT OPERATION ASSUMPTIONS
Multiple-Waves (Two 4-day Waves)
No Initial Encroachment
Initial Release of 8,000 cfs (Maximum Power)
Initial Flood Release Delay of 10 Hours (Applied to Second Flood Wave if Flood Reservation was Evacuated)
4 Hour Response Time Matching Outflow to Inflow
Rate of Change of Release Increase - 5,000 cfs/hr to 25,000 cfs - 15,000 cfs/hr above 25,000 cfs Decrease - 5,000 cfs/hr
Folsom Dam Release - Existing Full Capacity of Main Spillway in Combination with River Outlets (60% Gate Opening) Power Release of 8,000 cfs (Full Capacity)
Surcharge as Prescribed by Emergency Spillway Release Diagram
Routing with

occur to set the bounds on the operation. These combinations and subsequent sensitivity routings were cast into a triangular distribution of error about the inflow-outflow function. These triangular distributions were typically asymmetric. Sensitivity runs were made to determine how many factors should be combined to capture approximately 95 percent of the uncertainty. Table 3 shows the operational criteria used to set the operational bounds on the inflow-outflow curve for an example alternative that include a detention dam at Auburn and reoperation of Folsom Reservoir. For each alternative analyzed, inflow-outflow curves with uncertainty bounds were developed to serve as input to the risk-based analysis. This outflow error distribution is incorporated in the EAD computations. The sampled discharge with error is treated as Folsom inflow. The outflow with error is found by sampling the triangular distribution defined about the most-likely outflow. It should be noted that for actual alternative functions, the uncertainty limits about the flat portion of the curve was zero when the outflow is the objective release. It was determined that there was no uncertainty associated with the actual objective release itself.

System Routing. The UNET program was used to perform the system routings for this study. This model was developed by Dr. Robert Barkau and is currently supported by the HEC. UNET simulates one-dimensional unsteady flow through a full network of open channels. To facilitate model application, cross section data are input in a modified HEC-2 forewater format.

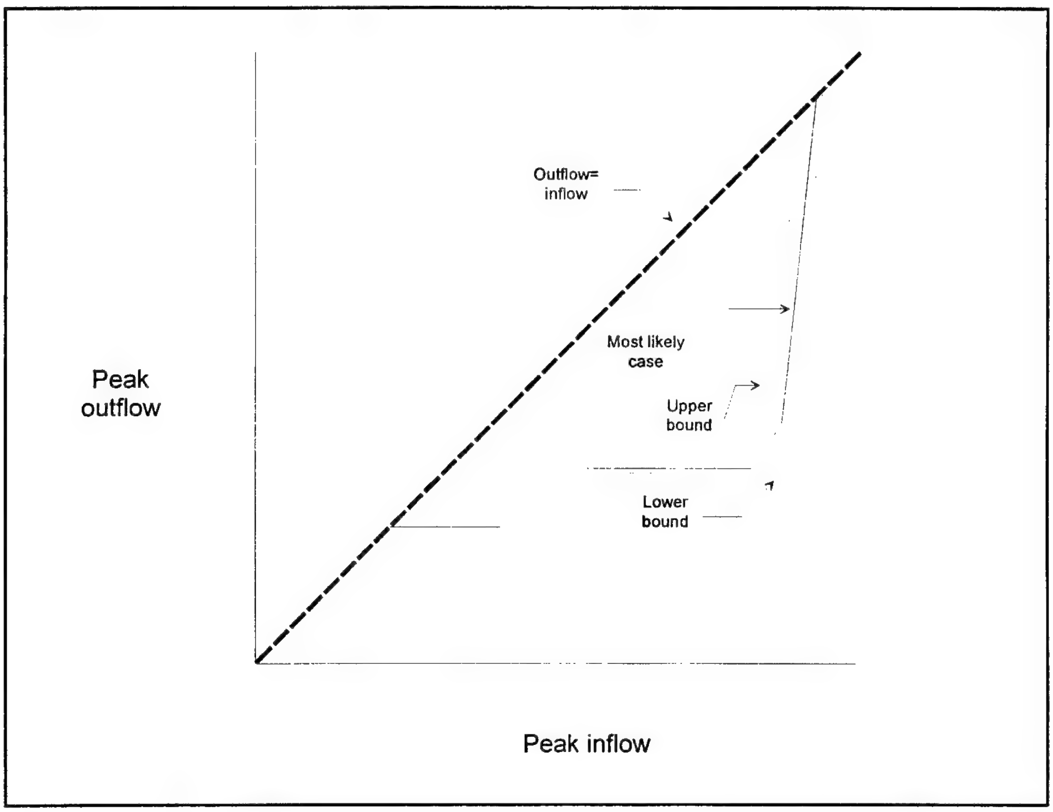


Figure 5 - Example Inflow-Outflow Function with "Confidence Bands"

Boundary conditions for UNET can consisted of stage and flow hydrographs which were read in from any existing HECDSS (Hydrologic Engineering Center Data Storage System) data base. The Sacramento River, American River and Yolo Bypass models were combined into one large model. The ability to use one model affords the advantage of making a change at one location and see how that change affects the rest of the system. The UNET model contains 29 river reaches. The 1986 event was used to calibrate the model since it was the largest flood of record at many locations, a large amount of field observations exist, and a large network of stream gaging stations were in place during the flood to measure flows and stages at many locations.

Table 3
Folsom Dam Operation Uncertainty Evaluation
Alternatives Including an Existing Reoperated Folsom Dam and Detention Dam

	Operations Conditions		
Factor	**Base**	**Maximum**	**Minimum**
Extra Space in Folsom Lake	0	0	100,000 Ac-Ft
Flood Waves	2	2	1
Upstream Reservoir Space	0	0	150,000 Ac-Ft
Outlet Works Operation	60%	0%	60%
Spillway Efficiency	Free Flow	3 Ft Surcharge	Free Flow
Initial Delay in Releases	10 hours	24 hours	0

Stage-Discharge Functions. The HEC-2 computer program, "Water Surface Profiles" (Version 4.6 - May 1991) was used to compute water surface profiles for the existing Lower American River system and for potential levee upgrades along the Lower American River. An HEC-2 model of the American River from Nimbus Dam to its confluence with the Sacramento River was developed for and utilized in a Flood Insurance Study (FIS) of Sacramento City and County in 1989. This model utilized cross sections surveyed by California Department of Water Resources (DWR) downstream of River Mile 14 and by CESPK upstream thereof. Cross sections of bridges were either taken from construction drawings or field surveyed. The model was calibrated using high water marks recorded during the February 1986 flood event. The starting water surface elevations for the study were developed via the UNET model of the American and Sacramento Rivers confluence area assuming no upstream levee failures on either the American or the Sacramento River systems. Several types of energy loss coefficients are used in the HEC-2 model for computation of head losses between cross-sections. These losses include boundary roughness associated with type and amount of vegetation, channel configuration, and channel meander, changes in the shape of the

river channel, such as contractions and expansions of the floodway, and bridge losses associated with pier number and type and flow type (pressure, etc) and entrance and exit conditions. The calibrated model has a SWSEL of 31.3 feet and discharge at the Sacramento River of 144,500 cfs and upstream of the NEMDC the discharge is 130,000 cfs. This represents the peak flow of the 1986 flood event.

Stage-Discharge Uncertainty. Uncertainty in stage was determined through a sensitivity analysis for defining the upper and lower limits for the one-percent chance event. The sensitivity analysis included adjusting the Manning's roughness coefficients, sediment accumulation, bridge blockage, and error in cross-section definition, starting water surface elevation, cross section geometry, debris on bridges, and scour. This hydraulic sensitivity analysis includes computation of the standard deviation of the stage differential, for the maximum and minimum conditions assuming higher objective releases from Folsom Dam. The base condition water surface profile, for each higher objective release from Folsom Dam, was compared to the corresponding water surface profiles resulting from the combination of hydraulic parameters to be tested which produce either the maximum or minimum conditions. This comparison identifies the sensitivity of the stage to the variance of the combination of hydraulic parameters. The cumulative maximum condition for all hydraulic parameters included modeling for debris on bridges, increased roughness ("n" values increased 15%), sediment deposition, 10% variance in geometry horizontally (except at bridges), and increased starting water surface elevation. This cumulative maximum condition resulted in a profile that was 1-foot higher at the downstream end of the American River and approximately 2-feet higher than the base condition at the upstream end of the study limits. The cumulative minimum condition for hydraulic parameters tested roughness (n values reduced 15%), 10% variance of each cross section horizontally, and starting water surface elevation for sensitivity to stage. Given the range of the computed water surface stages from 2 feet higher to 1.5 feet lower than the base, a standard deviation for the uncertainty in stage was selected at 1.0 feet.

Stage-Frequency Functions. Given the complexity of the Sacramento and American Rivers system, it is not possible to define a unique set of discharge-frequency and stage-discharge relationships at all index points. It was therefore necessary to develop stage-frequency functions at each index point where this condition exists. The stage-frequency curves were developed by combining observed data (at "base" locations where stage data exists) with 100-, 200- and 400-year stages computed by UNET at the actual index point. Base stage-frequency curves were developed for the Sacramento River at Verona, I-Street and Snodgrass Slough and for the Yolo Bypass at Woodland and Lisbon. Therefore, the stage-frequency function is made up of observed data in the high frequency range and computed stages in the low frequency range (See Figure 4).

1) Observed Data. The observed data for each base curve were plotted using Weibull plotting positions. The stage-frequency curve was drawn graphically through the points. The observed data at the base curve locations were translated to the index point locations based on the difference in the water surface profile of the 1986 flood between base curve location and other index point locations.

2) Computed Data. The development of the 100-, 200-and 400-year flood contribution from the Sacramento River required an understanding of what causes high stages at the

Sacramento-Feather River Confluence (SFRC). A review of several large floods revealed that a large number of flow combinations from the Sutter Bypass, Sacramento River and Feather River can occur. Therefore, a volume-frequency relationship was developed at the SFRC, which reflects the many concurrent flows that have occurred historically. The 100-, 200- and 400-year floods were calculated using this relationship. The eleven largest floods from 1929-1988 (59 years) were chosen to determine the volume-frequency curves. Historic hydrographs were developed to reflect the routing effects of the upstream flood control reservoirs. These hydrographs were routed using HEC-1, to the Sacramento-Feather River confluence to obtain peak and volume flows at this point. The 100-, 200- and 400-year points on the stage-frequency curves were computed using the UNET model. The stage resulting from the 100-year American and 100-year Sacramento was used as the 100-year stage for all index points for all alternatives. For the 200- and 400-year events, the combination that resulted in the highest stage for the given event was used.

Uncertainty in the Stage-Frequency Function. The observed and computed data required to construct the stage-frequency functions are used as input to the LIMIT program. LIMIT combines and calculates the uncertainty about the non-analytically derived frequency curve. LIMIT can be used when a frequency curve is developed based on systematic observations, hypothetical events, or both. Input to the LIMIT program consists of a stage-frequency curve, equivalent years of record for the systematic record and hypothetical events, and the estimated model error for the computed portion of the function.

1) Systematic Record. The equivalent years of record for each index point is based on the actual period of record of the base curve for that point. The equivalent years of record were computed using Interim Guidelines presented in Engineering Circular (Planning Guidance A-11) at HEC workshop on Risk and Uncertainty in February 1993. The guidance presents several ways of estimating the equivalent years of record. The most appropriate for base gage locations was using the adjustment corresponding to a long period gage within the watershed with the model calibrated to a gage based location. This adjustment calls for the equivalent years of record to be 50 to 90 percent of the actual record. The equivalent years of record ranged from 35-44 years depending on location.

2) Hypothetical Events. The stages for the 100-, 200-, and 400-year hypothetical events were computed, by UNET, from hydrographs derived from the volume-frequency analysis at the Sacramento-Feather River Confluence (SFRC) described earlier. The volume-frequency analysis at the SFRC is based on 59 years of record. The adjustment corresponding to a long period gage within the watershed with the model calibrated to a gage based location was used to determine the equivalent years of record. Since the volume-frequency analysis involved routings, which may further decrease the reliability of the values, 70 percent of the record, or 41 years, was used for the equivalent years of record.

3) Estimated Model Error. In order to determine the estimated model error in the hypothetical portion of the stage-frequency curve, a sensitivity UNET analysis was performed. Invert elevations were increased and decreased by 2.5 feet which is half of the contour interval. N-values were increased and decreased by 25 percent. These adjustments were run separately and in

combination with each other. Analysis of the results determined that the most reasonable error range is + or - 1.0 foot, or 2 foot total error range. In other words, the error band about the hypothetical elevations is one foot on either side. The model error is input to the LIMIT program as 25 percent of the total error. Using a 2-foot total error, the model error was set at 0.5 feet.

GEOTECHNICAL ANALYSIS

General. One of the elements considered in the risk and uncertainty analysis is the uncertainty in levee failure. According to the Engineering Technical Letter 1110-2-328, "Reliability Assessment of Existing Levees for Benefit Determination", the PNP is defined as the stage elevation below which it is highly likely that the levee would not fail. The PFP is defined as that stage above which it is highly likely that the levee would fail. The target stage for reliability computation, as described, typically represents a stage at which significant damage initially is incurred. For an existing levee, that stage is greater than the PNP stage and is less than the PFP stage, but is not known with certainty. The design parameters used in evaluating the stability of the existing levee system were determined by geotechnical evaluation and investigation.

American River Levees. There are approximately 22 miles of levee protecting the land north and south of the American River. For the Lower American River project reach, the PNP/PFP values were determined primarily by using the slope stability criteria developed in a 1988 report and levee performance during the 1986 flood. An evaluation of landside slope instability were conducted at each cross section. It was determined that for a levee section to be considered stable, three criteria should be met. These criteria include: 1) a minimum of 3 feet of freeboard; 2) an estimated steady seepage water exit height above the landside levee toe of no more that 0.6 foot; and 3) a hydraulic head difference between flood stage and the adjacent landside levee toe of no more than 6.0 feet. With consideration of 1986 levee performance, the PNP values along the lower American River are determined at least equal to the 1986 flood level, which is equivalent to a flow of approximately 130,000 cfs.

Sacramento River Levees. The Sacramento River project areas include the left and right bank levees starting from Rio Vista to Verona. Including both banks, this reach includes a total of 134 miles of project levees. The selection of the PNP and PFP values are based on the evaluation of existing levee profiles, the design water surface profile, and the estimated 1986 flood profile. For much of the levee reach, the selected PNP/PFP values were based upon past performances, i.e. the system passing previous floods near the design flood level. Levee modifications were performed in several miles of left bank levee above Freeport. As a result of the repairs made, the PNP and PFP values in these areas are higher than the rest of the study area. The higher PNP and PFP values were selected based on analytical approximations and judgement of the effects of a higher water surface on the modified levee cross sections. In project locations where landside berms were constructed, the height of the inclined drain is typically one-third to one-half of the height of the levee. The estimated increase in the seepage line through the levee resulting from a 2-foot higher river stage is minimal and has little impact on slope stability. Also, because the foundation soils of levees are predominantly fine grained and clay, the overall threat of foundation piping, in areas of berm construction, is minimal. Along the levee reaches where slurry cutoff walls were constructed, PNP

profiles vary from 1 to 5 feet from the top of cutoff wall because of the varying levee height.

Yolo Bypass Levees. The determination of PNP and PFP values along the Yolo Bypass was handled differently from the reaches of American River and the Sacramento River. The Yolo Bypass is not considered as part of the flood control system that will receive increased flood protection from this project. The area was only analyzed from a hydraulic mitigation standpoint. The intent of the hydraulic mitigation work is to remedy the impacts due to the increased objective release from American River so that the additional flow will not worsen reliability of the existing flood control system. The important calculation is the relative change in the system reliability in the hydraulic mitigation areas to determine if there is an impact. Therefore, along the Yolo Bypass, the PNP level was set at stages equivalent to the existing design water elevation. This is based on the assumption that even though the existing levee system has some known geotechnical problems, measures such as floodfighting would be executed to pass flows up to the design water surface.

ECONOMIC ANALYSIS

The economic analysis is based on October 1995 price levels, 7 5/8 percent interest rate, 100 year project life and future growth conditions from 1995 to 2008. Damage categories included residential, commercial, industrial, public, agricultural, emergency costs, and auto. HEC computed the damage-frequency relationships using the Structural Inventory for Damage Analysis (SID) computer program. The structure inventory was entered into the SID program to develop elevation-damage functions by category. The overall study had two damage assessment index points, one for the Natomas area, Index Point 2 and one for the greater Sacramento area, Index Point 7. The Sacramento Index Point was composed of five subreaches - Northern Sacramento, Rancho Cordova, South Sacramento, and Richards Boulevard. There were no uncertainty estimates used for this analysis for the economic parameters.

EVALUATION PROCESS

After configuring the initial seventeen potential measures into the eight initial alternatives, an initial risk-based was performed for two basic reasons. First, for alternatives that included increased releases from Folsom Reservoir, hydraulic impacts to the downstream system needed to be evaluated. As compared to the base, or existing system performance matrix, if there was a decrease in the levee reliability or true exceedance at any given index point, hydraulic mitigation features were included into that alternative and the cost adjusted. Additionally, once a full alternative was structured and the associated costs, the EAD and net benefits were determined to narrow the array of alternatives. The final array of alternatives reduced to four as shown in Table 1. A final incremental analysis was performed on these final plans cycling through the measures that made up that alternative to ascertain which features were the most cost effective or incrementally justified.

RESULTS

The analysis revealed a clear and substantial difference in the flood reduction benefits afforded by increased upstream storage as opposed to increased Folsom outflow releases and modification to the downstream system. The annual net benefits for the detention dam and the increased downstream system is $109 million and $77 million, respectively. The probability of failure in any one year is less than 1 in 500 for the detention dam and 1 in 235 for the increased downstream system plan. Table 4 presents a summary of the evaluation for the No-Action and the three finalist alternatives.

EPILOG

Political fallout, total project costs and environmental issues suspended the decision on selection of an alternative. Features common to all alternatives have proceeded to the design phase and those features will be constructed in FY98.

Table 4 - Summary of Risk Based Analysis

	Alternative			
	No-Action Plan	Folsom Modification Plan	Folsom Stepped Release Plan	Detention Dam Plan
Probability of Flooding in any one year	1 in 100	1 in 180	1 in 235	< 1 in 500
Probability of Passing a 200-yr Flood Event (%)	16	54	68	97
Benefit Summary				
First Cost ($ Million)	-	470	627	949
Annual Cost	-	49	72	95
Annual Benefit	-	126	130	204
Annual Net Benefit	-	77	58	109

AMERICAN RIVER PROJECT
LOCAL SPONSOR PERSPECTIVE

by: Paul T. Devereux, P.E.[1]
Director of Engineering
Sacramento Area Flood Control Agency

I. BACKGROUND

Flood Control History

The City of Sacramento sits at the confluence of the Sacramento and American Rivers. Together, these rivers drain an estimated 1860 square miles including over half the State of California and a portion of Oregon. As with most western cities in the 1800's, Sacramento was located near the river for transportation purposes. Before there were highways, airports and even trains, the river was the source of life. It provided water to drink, irrigate crops, raise animals and a means of contact with the outside world. Yet as much as the river was needed to live, it was also a deadly enemy. Sacramento has been battling the rivers since even before its birth. In fact, the entire Central Valley of California was known as an inland sea during many winters. Floodwaters would stretch for hundreds of miles from Redding in the north to the San Francisco Bay in the south and from the foothills of the Sierras on the east to the Coastal mountain ranges on the west.

Men and machines have constantly battled these floodwaters. The first public levee protecting Sacramento was built in 1849, the year after the City was incorporated. Since then, a variety of Federal, State and local agencies have tried their hands at protecting the City. SAFCA, or the Sacramento Area Flood Control Agency, working with the Corps of Engineer's and the State Reclamation Board is our generations attempt to control the River.

SAFCA is a joint powers agency which was formed by the City and County of Sacramento, Sutter County, the American River Flood Control District and Reclamation District 1000. The agency has a 13 member Board of Directors representing the five parent agencies. SAFCA has all the same powers held in common by the five entities. It also has the authority to assess benefitting properties to finance flood control projects, including the local share of federal flood control projects. The agency was formed in 1989 following the major flood of 1986 on the Sacramento and American Rivers. By organizing a single regional flood control agency, the Sacramento area felt it had the best opportunity to secure a Federal flood control project. It also provided a single unified local sponsor

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to work with the State and Federal government. Unfortunately, as time passed so did the memories of floodwaters lapping at the tops of levees. Flood control lost its right to step forward in the aftermath of the flood and the will to achieve consensus was lost as age old idealogies on the right project once again raised their heads.

Social Issues

Sacramento is now caught in a changing paradigm, along with the rest of the nation, following major floods in the Midwest, the South, Northwest, South Dakota and now Northern California. The Galloway Report, which was in response to the 1993 Midwest floods, recommends allowing rivers to reclaim their natural floodplains rather than push and shove them unwillingly into the straightjacket levee system. But this policy raises the difficult question of how do we deal with existing urban areas such as Sacramento with over 400,000 people within reach of the rivers floodwaters.

Secondly, who should pay for this flood protection. Should the State taxpayer in Los Angeles or the Federal taxpayer in Wisconsin be expected help subsidize a major flood control project in Sacramento. One could argue that Sacramento tax dollars were spent repairing earthquake damaged freeways in Los Angeles and providing assistance during deadly blizzards in Wisconsin. Also, based on the damages avoided and the assumption that the Federal and State governments will pay, at least in part, for disaster relief; the answer is yes, since money invested in flood control infrastructure in Sacramento will return benefits in disaster relief assistance avoided in the future. In essence, it represents a good investment of the Federal dollar.

Finally, how much flood protection is enough? We cannot guarantee every citizen in this country to be safe from every natural disaster. How much risk are we willing to live with? Sacramento has over $43 billion in damageable property in the floodplain today. The Corps estimate is that damages could be in excess of $7 billion in a 100-year flood. SAFCA has adopted a policy of seeking at least 200-year flood protection in this urban area. This is consistent with the recommendations from the Galloway Report urging Standard Project Flood protection in urban areas.

The Local Sponsor's Role (or Where the Rubber Meets the Road)

Before getting into the details of the American River Project I think a little perspective of how the local sponsor fits into the scheme of Reconnaissance and Feasibility studies, Principles and Guidelines, NED, Division Engineer's Notices, Chief's Reports and the like. As the title above suggests, the local sponsor is where the first political decisions must be made. The Corps has its guidance and regulations to resolve technical issues. However, it is the local sponsor who must sort through this world of engineering graphs and charts and make it seem real for the public and the local officials who eventually must choose a project they are willing to support and assess their constituents to fund. The Corps' job, then, is to provide the clearest road map which has enough information to find a route, but not overly detailed so as to create confusion. This has been the most significant disconnect on the American River Project. The issues have either appeared to be too

abstract i.e. a (500-year flood) or their relative importance has not made them a priority in the average citizen's life.

Therefore, it becomes the responsibility of the local sponsor to give the Corps clear direction at critical junctures in the study such as during alternatives evaluation, plan formulation and at conclusion of the Draft Feasibility as to which projects are viable economically, socially and politically. And it is equally important for the Corps to listen to these messages and find a way within their regulations to make a project happen. It should be the common goal of the Corps and the local sponsor to get a flood reduction project in the ground. Each side may have to give a little along the way. The Corps may need to bend the rules from time to time to get an alternative which works for the sponsor, and the sponsor needs to understand the Corps has rules to insure projects from around the country are treated equally. For example, the Corps method of evaluating economic benefits of a flood control project may lead to an NED project which provides unequal levels of flood protection on opposite sides of a stream or in different areas of the community. This may be due to differences in the number of structures protected or the relative economic circumstances of each neighborhood. However, the sponsor will most likely demand that a flood control project should treats all of its citizens equally, irrespective of their economic basis. A compromise might be to agree on a project which costs the same as the NED project but which provides a consistent level of flood protection somewhere between the two unequal levels of protection in the NED plan.

The local sponsor is the first point of contact for the public since they are close to home and generally more familiar than State or Federal representatives. It becomes the arena where the battles are first waged and attempts to reach consensus must be made. Such was the case on the American River project. These attempts proved unsuccessful and eventually spelled defeat at the Federal level, at least in the first two attempts. The Federal officials were always looking to the locals to choose a project which had broad support and bring it to Washington with an agreement at hand. At the local level, elected officials looked to their counterparts in Washington to "make the deal".

Finally, the local sponsor, in making its choice, must balance the often diverse needs of the community. Yes we need more flood control, but we also need new roofs on school buildings, and more police to patrol our streets. The local sponsors often have to weigh the need for economic growth, jobs and accommodating an influx of new residents into a region with good floodplain management. Is it better to locate far from the river and the dangers of flooding, but put more cars on our highways and more pollution into the air? The answers always seem simple in the aftermath of a flood. Let the rivers be joined with their natural floodplains is the outcry. New development should not be allowed in flood prone areas. But what are the answers in urban areas like Sacramento where the central business district and extensive urbanization already exists in the floodplain?

II. AMERICAN RIVER PROJECT

Historical Flood Protection

In 1955, with the near completion of Folsom Dam and the downstream levees, Sacramento was thought to have 250 to 300 year flood protection. However, in December 1955, just months before the newly constructed reservoir was to begin operations, a major storm hit Northern California. Heavy rains caused uncontrolled flooding in the Feather River Basin north of Sacramento causing extensive property damage and loss of life. On the American River, the flood filled the new reservoir in only four days, a feat the designers expected would take several months to accomplish. Two similarly large storms followed in 1963 and 1964, causing the Corps of Engineers to reevaluate the flood protection afforded by Folsom. By including this new hydrologic information in the calculations, the Corps estimated the flood space in Folsom and the downstream levees could only contain about a 120 year storm. Efforts to improve the situation were tied to the planned multi-purpose Auburn Dam which was authorized in 1965 with construction commencing soon thereafter. An earthquake in nearby Oroville in 1972 stopped construction and raised questions as to seismic safety at the Auburn site. Despite a panel of experts finding in 1979 that a safe dam could be constructed at the Auburn site, new federal cost sharing policies for water and power projects adopted in 1980, prevented the Auburn project from getting started again.

1986 Flood

Sacramento was destined to wait for the next flood to awaken the memories and push for improved flood protection. That flood came in February 1986. After a very dry winter, a series of Pacific storms nicknamed the "pineapple express" because of their origin near the Hawaiian Islands carried wave after wave of warm rain to Central and Northern California. Folsom Dam quickly filled and reservoir operators were forced to release 134,000 cfs, exceeding the design release of 115,000 cfs for over 36 hours. Meanwhile, downstream levees contained the record flood flows with boils and seepage evident at several locations. Extensive erosion along the levee toe occurred to both the north and south levees of the American River near California State University, California.

Along the Sacramento River, the levees fared worse. Like the American River, record stages were recorded at the I Street Gage adjacent to Old Sacramento. Levees in the Natomas area near Sacramento International Airport experienced considerable seepage and erosion along the landside. Only a determined flood fight prevented collapse of the east levee of the Sacramento River (which protected more than 35,000 residents of the Natomas area). Fortunately for Sacramento, the rain slowed just in time. Inflows to Folsom Dam finally dropped. Had the rains continued even for a few more hours, the releases at Folsom were to be increased to 150,000 cfs which would likely have led to catastrophic levee failure in the heart of Sacramento, significant property damage and a potential for loss of life. Based on what we have learned about our system since 1986, there probably should have been an evacuation of the American River floodplain that February day.

Significant flooding did occur in the Strawberry Manor neighborhood, a low income area in North Sacramento adjacent to Arcade Creek. Floodwaters outflanked the levee system upstream as well as leaking out of the levees at a nearby road crossing below the top of the levee. In addition, large low lying areas were flooded in Roseville and Rio Linda/Eleverta in northern Sacramento County along Dry Creek. Finally, flooding occurred in agricultural lands north and east of Sacramento from a combination of high river stages.

System Re-evaluation

After the 1986 flood, the Army Corps of Engineers initiated a comprehensive evaluation of the entire Sacramento River Flood Control System. The first phase of this evaluation focused on the east levee of the Sacramento River, which protects Natomas, Downtown Sacramento, and the urbanized areas to the south. As previously discussed, these levees were constructed in the early 1900s, using material dredged from the river channel. Due to the sandy quality of this material (much of which was deposited in the river bed during the hydraulic mining era in Northern California) and poor compaction methods, the Corps determined that 33-miles of levee along the Sacramento River between Freeport and the mouth of the cross channel were structurally deficient.

Without remedial work, the Corps concluded, high flows in the Sacramento River could produce enough seepage through the levees to trigger a breach. The east levee protecting Natomas between the mouth of the American River and Verona, where severe seepage and a near breach occurred in 1986, was found to be particularly vulnerable; the east levee south of the American River to Freeport was reported to be in slightly better condition, but still in need of repair.

In addition, the Corps re-evaluated the frequency of flooding in the American River Basin. As previously noted, prior to 1986, Folsom Dam and the lower American River levee system were thought to provide a 120-year level of flood protection to the residents and businesses occupying the American River floodplain. After the 1986 flood, using data gathered from the storm itself and hydrologic information compiled since the construction of Folsom, the Corps downgraded the system's flood control capacity to a 63-year level. This meant that there was a greater than 1.6 percent chance *in any given year* that a flood event would exceed Folsom's capacity. It is also interesting to note, the seven largest floods of this century all occurred after construction of Folsom and therefore none were considered in the design of the reservoir (Attachment A).

The Corps also concluded that the levees along the Natomas East Main Drainage Canal (NEMDC), which protect Natomas and the Dry Creek area to the east, were too low to safely contain the flows produced by the coincidence of peak discharges in Dry and Arcade Creeks and maximum flood releases from Folsom.

As a result of these findings, the Federal Emergency Management Agency (FEMA) reassessed the 100-year floodplain in the Sacramento area and issued new Flood Insurance Rate Maps (FIRMs). These maps, which became effective in November 1989, mandated the purchase of flood insurance

by all residents and businesses within the 100-year floodplain and caused the City of Sacramento to impose severe restrictions on new residential development in the Natomas area.

What's at Risk?

The overlapping American and Sacramento River floodplains encompass a land mass of more than 100,000 acres. About half of this land lies within the Natomas Basin, an agricultural reclamation district that has experienced significant development pressure during the past two decades and now contains over $2 billion worth of damageable residential, commercial and industrial property, including Sacramento International Airport.

Outside Natomas and the Dry Creek area immediately east of the basin, the floodplain straddles the American River. To the north, it covers about 6,000 acres, including the state fairgrounds at Cal Expo, the Campus Commons subdivision, and a portion of North Sacramento near McClellan Air Force Base. South of the American River, the floodplain covers about 45,000 acres, encompassing much of downtown Sacramento, the State Capitol, California State University campus, the City's water treatment facilities, the River Park neighborhood (adjacent to the river northeast of the downtown core), and a number of large residential areas to the south.

Although the Corps has estimated that this section of the floodplain outside Natomas and Dry Creek contains over 300,000 residents and $30 billion worth of damageable property, grade elevations for most of this area are significantly lower than water surface elevations in the river channels during major floods. Thus, the potential exists for extensive deep flooding in the event the levees are overtopped, or if they otherwise fail due to prolonged high flows. As a result, the Corps estimates that a levee failure along the American River could cause as much as $9 billion worth of damage in Sacramento, slightly more than the losses attributable to the 1989 Loma Prieta earthquake in the San Francisco Bay Area.

Action Plan

Out of the ashes of the 1986 flood came a strategy to address the significant and unacceptable flood risk in Sacramento which was embraced by federal, state and local officials.

1. Stabilize and strengthen the existing system;
2. Temporarily use Folsom Dam and Reservoir for more flood control storage space;
3. Plan and implement a long term project providing Sacramento a high level of flood protection.

The first two goals of the strategy have either been accomplished or are in progress. When the strategy was first developed, the intent of the first task was simply to rehabilitate the Sacramento River levees. This was accomplished by placement of a landside berm, or through placement of slurry wall down the center of the levee. Unfortunately, as time passed, we have found the need to repair and replace components of the existing system are an on-going, and possibly never ending series of tasks. For instance, in the summer of 1995, a radial gate at Folsom dam broke spilling

40,000 cfs into the downstream system in July. During the 1997 flood, serious damage was found in the low level river outlet tubes at Folsom caused by cavitation; and the stilling basin below the emergency outlet gates was also damaged. The Corps has now determined the American River levees are in need of work to reduce the risk of seepage and catastrophic levee failure during periods of high water. The Corps is now in the final design stages of a project to place the slurry walls in all the American River levees downstream of Folsom Dam to address the seepage and stability concerns.

The rehabilitation efforts are not limited to the major river systems such as the Sacramento and American Rivers. SAFCA has recently raised and/or constructed new levees along approximately 20 miles of channels protecting the Natomas basin and North Sacramento. SAFCA is also partnering with the Corps on projects in South Sacramento and Magpie Creek; both existing flood control projects which are now deemed inadequate primarily due to changes in hydrologic assumptions.

The second goal was accomplished via an agreement between SAFCA and the Bureau of Reclamation. Under this agreement, sufficient space is to be maintained at Folsom together with existing space in the three largest upstream hydro-power reservoirs to contain the 100-year flood. If the operation resulted in any water, power, or environmental impacts, SAFCA will compensate the impacted user.

The last goal in the strategy has proven to be the most elusive because of its nexus to Auburn Dam. The choices for long term flood protection essentially come down to three options; dedicate more space at Folsom for flood storage; make major modifications to the existing system (i.e. raise levees, re-configure the outlet works at Folsom) in addition to increased flood storage capacity; or add new storage to the system by building another dam.

As I said, immediately following the flood, the need for improved flood control took center stage and it seemed a compromise project would quickly move forward in the process. That compromise project was a "dry dam". The dry dam would only hold water in the winter during a major flood, and only for a brief time (estimated at 21 days for a 400-year flood). However, this dam would be constructed in a manner that it could be expanded into a multi-purpose dam as envisioned by long time supporters of the original Auburn Project. However, as time passed and memories of the 1986 flood faded, so did the will for the diverse interest groups to compromise and reach consensus. People returned to their polarized positions on Auburn.

There were those who only wanted a multi-purpose Auburn dam and felt money spent on a "dry dam" was wasteful. They also felt strongly that once Sacramento solved its flood control problem, the momentum for the big dam would be lost along with the commitment of federal dollars. By contrast, the environmental interests who wanted no dam at the site saw the dry dam as the proverbial "camel's nose under the tent". Once a dam was built in the canyon, they surmised, under interests would figure a way to permanently store water behind it. With this "horseshoe alliance" joining forces (and subsequently being joined by taxpayers groups) in 1992 to oppose the project in Congress, the project was doomed to failure.

Similar efforts were remounted in 1996 following the change in political leadership in Congress following the 1994 elections. This time, the supporters of the multipurpose dam were in support of the dry dam as the first step towards the big dam. Despite this support, the environmental and fiscal conservative interests were again strong enough to stop the project. The only elements of the plan which were eventually authorized by Congress were those features which were needed irrespective of whether the project was a dam at Auburn or improvements to the existing system. These features were termed the "Common Elements".

Future Efforts

Following the defeat in 1996, SAFCA, the State and Corps are in the process of reanalyzing our position. One thing is clear, no project will move forward which does not have a broad range of support. This includes consensus at the local level, support from both political parties in Congress, as well as support (or at least not opposition) from the impacted special interest groups such as the water users and environmentalists. It is much easier to stop a project from moving through the process than it is to actually make a project happen. Therefore, our next goals are to identify those specific elements which can garner this base of support.

The most likely candidate is some modification to Folsom's outlet works. All agree the current configuration with the spillway crest very high on the reservoir is very ineffective. The low level outlet capacity of the reservoir is limited to a maximum release of 35,000 cfs which is much below the downstream design release capacity of 115,000 cfs. In fact, the reservoir must reach a storage capacity of almost 800,000 acre-feet (halfway encroached in the flood storage space) until the releases can match the downstream capacity. By enlarging the size of the low level outlet gates and adding four additional outlets, the release capacity could be increased to approximately 70,000 cfs at reservoir levels below the spillway crest.

This improvement would benefit downstream interests by allowing increased releases earlier in a storm reserving more space to contain larger floods. For upstream interests who are adversely impacted by low reservoir levels when floodwaters are released and not replenished, this modification could also be of benefit. With the ability to release larger amounts of water early in a storm, operators could allow a fuller reservoir during the flood season and make anticipatory releases based on weather forecasts or maybe even after actual rainfall has been measured. This would allow the reservoir to remain at higher levels in the later winter and early spring thus increasing the chances for full recharge or at least insure the reservoir would be at higher levels in the summer than it is with the existing configuration and flood capacity.

III. RISK BASED ANALYSIS

Measuring Risk

Since the topic of this workshop is risk and uncertainty. It is appropriate to talk about both. When we think of risk what comes to mind is the fact we are taking a chance on something in which the

outcome could be adverse. The parallel is luck in which we are taking a chance and something good could happen to us. Flood control is certainly a risk. Each year we are taking a chance with the consequences of losing being catastrophic flooding, huge property damages and potential for loss of life. In Sacramento, even with the current agreement on flood storage space at Folsom, there is greater than a 1% chance of a major flood in Sacramento **each** year. Over a 30-year period, this equates to a greater than 1 in 4 chance we will experience catastrophic flooding.

Yet, in the minds of the general public, this risk is not real. Yes there are areas which have flooded, but generally they are the same areas which always seem to flood. The bulk of the populace sits behind the levees oblivious to the potential risk. Over the past six years working in Sacramento, I have been approached by literally dozens of people who confidently proclaim they have never flooded since living in their houses and therefore do not believe they are at risk of flooding in the future. Though I quietly remind them we have not had a 100-year flood in modern times on the American River, they also remind me, each time we have a flood, the definition of the 100-year flood seems to change. Finally with the recent floods of last January 1997, in which levees were failing up and down the system on a daily basis, it seems the public as more aware of the risk living behind levees. The current media coverage of the El Nino condition in the Pacific has further heightened the public's concern about flood risk. Flood insurance is becoming the newest hot commodity on the market.

The City of Sacramento in its Comprehensive Flood Management Plan published in 1996, tried to compare the flood risk in the City with other common risks. Attachment B shows the comparison. As one can see, the risk of flooding is far greater than other common risks such as a house fire, developing cancer or being involved in a fatal car accident. Despite this fact, almost all structures carry fire insurance, but only about one-third of the houses in the floodplain carry flood insurance. The risk is not real in the eyes of the public. The average citizen in this community believes they are at far greater risk of being a murder victim than of being a flood victim. Our challenge is to make the flood risk as real as the crime risk. The facts and message need to be delivered in terms which can be generally understood by the public at large.

In the preceding paragraphs where I discussed the alternatives to improving flood protection in Sacramento, there was mention of political parties and special interest groups. The group with the largest at stake, the floodplain residents, were not a force. They were a disinterested third party in the debate. It was the one group, which if mobilized, could have swayed the decision. Our challenge is to get this group of stakeholders to be active participants in the process.

Risk and Uncertainty

There are two areas where the Corps new method of planning and implementing flood control projects through the use of the risk based analysis has impacted the American River project planning process. The first is in trying to describe true risk and the levels of flood protection provided by the various alternatives studied. Sacramento and its elected officials have come a long way since 1986 in understanding how our complex flood control system works and what flood risk is about. We

have been able to break through the 100-year flood myth propagated by the National Flood Insurance Program. Under this myth, once there is greater than 100-year flood protection there is no longer a flood risk.

We have slowly been able to educate a portion of the community that flood risk does not disappear with 100-year protection. We have quantified 200- and even 500-year flood events. Protection provided by projects are now described in terms of the flood risk over a 30-year period (the typical life a mortgage on a house). For instance, even with 100-year flood protection the risk of flooding is still 26% over a thirty year period, over a 50 year period the risk is 40%--almost a coin toss. With 200-year protection, the risk is reduced to 14% over thirty years and with 400-year protection, the risk is reduced to just 7%. However, even with this correlation between level of protection and residual risk, the jargon which is still the most clearly understood is measuring projects by the levels of protection they provide (i.e. the true exceedance).

With the introduction of the R & U package, the concept of reliability was intermixed (Attachment C). Under this new way of describing flood control projects, a single number is not used for the level of protecion but rather each project has a certain "reliability factor" assigned that it can pass a given flood event. This concept, though more technically correct since it considers there are a number of uncertainties inherent in hydrologic and hydraulic calculations, does not provide a high comfort level for people used to dealing in absolute numbers. This concept becomes even more difficult when you take a particular project to the public and ask them to pay for it. How do we sell a project which may have a true exceedance of 200-year, but may have a reliabliity factor of less than 80% for passing this flood? Even worse, the same project may have a reliability factor such that it could not be certified as providing 100-year flood protection under FEMA's guidelines. Such was the case on the American River project, where the stepped release plan which had a true exceedance of 235-year protection but which may not pass the 100-year event with sufficient reliability to be certified under preliminary criteria being set forth by the Corps and FEMA.

To avoid much of this confusion on the American River project, we limited our discussions with the public and the elected officials to using the true exceedance values. Each of the alternative projects was described as providing a certain level of flood protection, (Attachment D) but to make the correlation to risk, the alternatives were compared in terms of flood risk over a 30-year period. The Folsom Modification Plan provided 180-year protection (17% risk), the Stepped Release Plan provided 235-year protection (15% risk); and the Detention Dam Plan provided 500-year protection (5% risk). Using these numbers, the elected officials, and members of the public who followed the process were able to quickly grasp the relative differences in terms of proteciton and costs while not losing sight of the residual risk which remains even with the projects in place.

The second issue which has surfaced with the use of the R & U package is what are the potential hydraulic impacts of these flood control projects where there really is no design flood level or design flood event? Under the previous design standard, a water surface elevation was set based on a design storm, and a freeboard factor (typically 3 feet) was added to establish a top of levee. In anlyzing the levee, it was presumed the levee would fail at some point when the water encroached into the

freeboard. Under FEMA's criteria, failure was assumed for any encroachment into the freeboard. Hydraulic impacts of the project on upstream or downstream properties were limited to analyzing the design event since larger events were presumed to fail the levee thus relieving the impacted properties.

Under the R & U method, there no longer is freeboard but a probable failure point (PFP) and a probable non-failure point (PNP). Floods below the PNP are assumed to be contained by the levee, floods with stages greater than the PFP are assumed to fail the levee while floods with water surface elevations between the PNP and PFP may or may not fail the levee and are assigned a weighted probability of failure in relation to the PFP and PNP. This now plays into the hydraulic impact arena, because it is recognized that levees may contain floods up to the PFP and therfore any hydraulic impacts of a flood up to the PFP level may be realized.

This very circumstance is the subject of intense debate between SAFCA and a number of property owners in the lower Dry Creek watershed (Attachment E). By constructing levee improvements protecting the Natomas basin, North Sacramento and portions of Elverta/Rio linda, the floodwaters which would otherwise flood these areas are now contained between levees in the lower Dry Creek floodway raising the water surface elevations for a given flood event in the post- vs. pre-project condition. In 1993, we analyzed the impacts of the project for the design flood event and found only a few structures in the lower part of the watershed would be impacted. SAFCA agreed to compensate these property owners for the loss of use of their property. In the end, we will end up purchasing these structures to eliminate future liability and to further the County and City's goal of creating a Dry Creek parkway.

However, when we were about to proceed with the last element of the project, completion of the south Robla Creek levee improvements in 1995, a group of property owner's above the impact zone identified in the 1993 hydraulic impact analysis challenged our conclusions. In their minds, we should analyze the impacts of larger flood events up to and including a flood to the top of the levees. Based on a cursory analysis, this would be on the order of a 1000-year event since our design criteria was to design a top of levee 3 feet above the 200-year water surface elevation.

As a way to move forward in 1995, we agreed to build a staged project and only complete the improvements after an analysis of the impacts due to larger than the design flood event. This decision was partially attributable to the new R & U standards applying to levee analysis. In our estimation, if the levees can be credited with providing flood protection with the freeboard area, then we should also consider the potential impacts of containing such a flood. Despite the demand to look at a top of levee flood, we limited the analysis to floods up to and including the 500-year flood which is the estimated PFP of the proposed levee. As expected, the analysis showed greater impacts of the project extending futher upstream. The new impact area at the 500-year includes approximately 80 homes, an apartment complex, and a small private airport.

The impacts, though real, have been determined to be small; generally 0.2 feet at the 100-year flood and 0.4 feet at the 500-year flood. Most structures impacted at the 500-year event are already

flooded by this event even without our project. We are increasing the depth of flooding on these already flooded structures.

We had an expected annual damage analysis done for these structures to determine if the potential damages imposed by our project warranted any mitigation. The total increase in EAD for all the impacted structures was only about $4,000. The cost to mitigate for the impact by protecting the structures with flood control measures would cost in excess of $1 million. SAFCA agreed to contribute a share of the mitigation costs if the property owners would cost share. Nevertheless, the Reclamation Board of the State of California stepped into the negotiations and has included a condition on our permit to construct the downstream levees which states we must mitigate any increase in EAD or decrease in level of protection attributable to our project.

Similar discussions are beginning on other Corps projects in the Sacramento area, most notably Magpie Creek Diversion and South Sacramento Streams Group where downstream properties will be impacted by more water being brought into the area. In at least one of these projects, the Corps has opted to use levee failure at the PNP rather than the PFP as the basis for determining hydraulic impacts.

RISK-BASED ANALYSIS FOR EVALUATION OF ALTERNATIVES GRAND FORKS, NORTH DAKOTA AND CROOKSTON, MINNESOTA

by

Michael Lesher[1] and Pat Foley[2]

Purpose and Overview

Risk-based studies for a proposed levee project for the Red River of the North at Grand Forks, North Dakota and for a proposed channel cutoff and levee project for the Red Lake River at Crookston, Minnesota used a Latin Hypercube analysis to sample the interaction among uncertain relationships associated with flood discharge and stage estimation. The write-up that follows discusses the sensitivity in the quantification of uncertainties, and the representation of risk for selected project levee heights. This work was done prior to: the development of the Flood Damage Analysis (HEC-FDA) computer program, the record flooding in 1997, and the 10 April 1997 Guidance on Levee Cetification for the National Flood Insurance Program memo from CECW-P/CECW-E.

Data and Uncertainty

Study Data. For the determination of simulation exceedence frequency, the project sizing option in the HEC spreadsheet was used since the reliability analysis does not provide simulation exceedence. This approach allows the determination of accurate simulation exceedence data not obtainable from the project reliability option in the risk spreadsheet developed by HEC. The uncertainty in the discharge-frequency, stage-discharge and stage-damage relationships and the impact on the project benefits is analyzed in the risk-based approach using the Latin Hypercube process. Latin Hypercube is a relatively new stratified sampling technique used in simulation modeling. Stratified sampling techniques, as opposed to Monte Carlo type techniques, tend to force convergence of a sampled distribution in fewer samples.

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Grand Forks

Discharge-Frequency Relationship. A USGS streamgage is currently located about 200 feet upstream from the DeMers Avenue bridge and 0.4 mile downstream from the Red Lake River in Grand Forks, North Dakota. Streamflow data with an equivalent record length of 112 years were used to derive the discharge-frequency curve at the gage. A Log-Pearson Type III distribution with a logarithmic mean of 4.1584, a logarithmic standard deviation of 0.3814, and a skew coefficient of -.20 was fit to annual peak streamflow data. This distribution is utilized directly in the Latin Hypercube analysis. The adopted computed and expected probability discharge-frequency curves are summarized in Table 1. The expected probability adjustment is not used for the Latin Hypercube simulations because the concept is explicitly incorporated when accounting for error in the discharge estimates. However, expected probability was utilized in the traditional analysis shown for comparison and the expected probability discharges were used to compute the water surface profiles on which the stage-discharge curve is based.

Uncertainty in discharge is associated with sampling errors in the mean and standard deviation for a stated exceedence. This method is often used to develop confidence limits for the discharge-frequency curve using the noncentral t-distribution, as defined by approximation equations (U.S. Department of Interior, 1982). With given values for parameters of the frequency curve (i.e.mean, standard deviation and skew), the sample size (i.e. years of record), and the exceedence frequency associated with a particular discharge, a distribution of errors about the given discharge is developed.

Table 1 - Grand Forks Feasibility Study Adopted Discharges - Annual Series June 1994		
Exceedence Frequency (percent)	Red River below Red Lake River Annual Peak Discharge (in cfs)	
	Computed Curve	Expected Probability
0.2	146,000	154,000
0.5	117,000	122,000
1.0	97,600	101,000
2.0	79,500	81,500
5.0	58,000	59,000
10.0	43,500	43,900
20.0	30,400	30,600
50.0	14,800	14,800
80.0	6.950	6,900
90.0	4,590	4,540
95.0	3,240	3,170
99.0	1,640	1,570

Stage-Discharge Relationship. The traditional Red River analysis defined the stage-discharge relationships utilizing the HEC-2 computer program. Resulting computed water surface elevations are shown in Table 2 for cross sections located at the previous and current U.S.G.S. gage locations. As noted earlier, these water surface elevations are based on the expected probability discharges. The water surface profile analysis was performed using cross-sectional data obtained from field surveys. Overbank data was also taken from field surveys as well as U.S.G.S. sheets. The model was calibrated to the U.S.G.S. streamgage data and to high water marks for the 1969, 1975, 1978, 1979 and 1989 flood events throughout the study area. Note that these elevations are based on a condition where the Grand Forks project is assumed to be in-place and encroachments on the East Grand Forks side are based on the adopted Flood Insurance Study floodway encroachments.

Table 2- Red River of the North at Grand Forks, North Dakota Computed Water Surface Elevations for Existing Conditions

Cross Section Number	River Mile	Minimum Channel Bottom in Feet	Grand Forks Project Assumed to be In-Place and East Grand Forks Encroachments based on Adopted Flood Insurance Study Floodway Encroachments							
			38-Percent (2.6-Year) CWSEL	27-Percent (3.7-Year) CWSEL	20-Percent (5-year) CWSEL	10-Percent (10-year) CWSEL	4-Percent (25-year) CWSEL	2-Percent (50-year) CWSEL	1-Percent (100-year) CWSEL	0.2-Percent (500-year) CWSEL
7790	295.70	773.15	811.10	814.30	817.20	821.70	825.00	827.30	829.60	834.80
7800	296.00	774.2	811.32	814.51	817.39	821.87	825.19	827.52	829.83	835.01
7922	297.55	774.60	812.26	815.41	818.26	822.74	826.27	828.83	831.58	837.25
44 (1)	297.65	772.40	812.38	815.53	818.39	822.91	826.67	829.18	831.84	837.59

(1) Current Location of U.S.G.S. gage.

Ratings at streamgage locations provide an opportunity to directly analyze stage-discharge uncertainty. The measured data are used to derive the "best fit" stage-discharge rating at the streamgage location, which generally represents the most reliable information available. In this study, the adopted rating curve corresponds to the computed water surface elevations using the calibrated HEC-2 model. The adopted elevations shown in Table 4 were obtained from this adopted stage-discharge rating curve.

If a single index location is appropriate for the flood damage reduction study, and a streamgage exists at that location, measurements at the gaged location may be used directly in assessing the uncertainty of the stage-discharge relationship. For this study, the U.S.G.S. gage has been located at four different sites in the study reach represented by the four cross sections presented in Table 2. The observed gage data was transferred to the current gage site at river mile 297.65 based on the adjustments presented in Table 3 which were computed from the water surface elevations in Table 2. These adjustments were plotted versus the corresponding discharge below the Red Lake River and curves were developed to obtain adjustments for other discharges. The adjustments in column 8 of Table 4 were obtained from these curves based on the discharge for the event in column 3.

Table 3 - Adjustments to Transfer Observed Elevations from Previous U.S.G.S. Gage Sites to Current Gage Site at RM 297.65 (XS 44)					
Probability	Expected Probability Discharge in cfs		XS 7790 RM 295.70	XS 7800 RM 296.00	XS 7922 RM 297.55
	Below Red Lake River	Above Red Lake River			
38-Percent	20,000	12,500	1.28	1.06	0.12
27-Percent	25,000	16,100	1.23	1.02	0.12
20-Percent	30,600	20,300	1.19	1.00	0.13
10-Percent	43,900	30,300	1.21	1.04	0.17
4-Percent	63,500	45,800	1.67	1.48	0.40
2-Percent	81,500	58,800	1.88	1.66	0.35
1-Percent	101,000	73,500	2.24	2.02	0.26

The deviations of the observed elevations from the curve were used to estimate the uncertainty of the stage-discharge rating curve shown on Plate 1. The deviations reflect the uncertainty in data values as a result of changes in flow regime, bed form, roughness/resistance to flow, and other factors inherent to flow in natural streams. Errors also result from field measurements or malfunctioning equipment. A minimum of 8 to 10 measurements is normally required for meaningful results.

The standard deviation for a data set may be computed as follows:

$$StandardDeviation(SD) = \sqrt{\frac{\Sigma\,(X-M)^{2}}{N-1}}$$

Where:

X = Observed Elevation Adjusted to Current Gage Location (if necessary)
M = Computed Elevation from Adopted Rating Curve
N = Number of measured discharge values (events)

The stage uncertainty was computed for two different discharge ranges for this analysis. Based on a plot of the observed elevations on the adopted rating curve, it was evident that there was greater uncertainty for discharges less than about the 10-percent event due to ice, downstream agricultural levees and other factors. Therefore, the standard deviation was computed for discharges greater than about 22,000 cfs, which approximately corresponds to the zero damage elevation based on the adopted rating curve, and less than 44,000 cfs, which is slightly greater than the 10-percent event computed probability discharge. The standard deviation was also computed for discharges greater than 50,000 cfs. During the 112 year period of record, there were 23 events with a discharge between 22,00 and 44,000 cfs and 9 events with a discharge greater than 50,000 cfs. The standard

deviation computations are summarized in the Table 4 below. As can be seen, the standard deviation for discharges between 22,000 and 44,000 cfs is 1.66 feet and for discharges greater than 50,000 cfs it is 0.50 feet. In the risk and uncertainty simulations, the standard deviation was linearly interpolated between 1.66 and 0.50 feet for discharges between 44,000 and 50,000 cfs. A vertical lookup table was added to the Hydrologic Engineering Center spreadsheet template to accomplish this.

Table 4 - Determination of Standard Deviation for flows between 22,000 & 44,000 cfs and for flows greater than 50,000 cfs

Station	RED RIVER OF THE NORTH AT GRAND FORKS, ND				Id - 05082500		
State	ND	Drainage Area	30100.0	Hydrologic Unit		9020301	
County	035	Contributing	26300.0	Years		1882-1991	
Latitude	47:56:34	Gage Datum	778.35	Continuous		Yes /No	
Longitude	097:03:10	Base Flow	4500.0	Ann/Par		Cnt 110 /118	

YEAR	DATE	DISCHARGE in cfs	Stage in Feet	Observed Elevation in Feet	River Mile	Gage Zero in Feet	Gage Location Adjust-ment in Feet	X Observed Elevation in Feet at RM 297.65	M Adopted Elevation-in Feet at RM297.65	(X-M) Observed minus Adopted RM297.65	$(X-M)^2$
1892	04/17/92	23,000	33.40	813.30	297.55	779.90	0.12	813.42	814.40	-0.98	0 9604
1951	04/12/51	23,600	33.52	811.94	296.00	778.42	1.03	812.97	814.75	-1.78	3.1684
1976	04/03/76	23,600	34.58	812.93	295.70	778.35	1.24	814.17	814.75	-0.58	0.3364
1952	04/21/52	23,800	33.60	812.02	296.00	778.42	1.03	813.05	814.80	-1.75	3.0625
1982	04/12/82	23,900	37.18	815.53	285.70	778.35	1.24	816.77	814.85	1.92	3.6864
1916	04/17/16	26,100	41.00	819.40	297.55	778.40	0.13	819.53	816.15	3.38	11.4244
1993	08/03/93	26,200	36.39	815.39	297.65	779.00	0 00	815.39	816.20	-0.81	0.6561
1962	06/16/62	26,600	34.45	812.80	296.00	778.35	1.01	813.81	816.40	-2.59	6 7801
1994	07/12/94	26,800	34.30	813.30	297.65	779.00	0.00	813.30	816.50	-3.20	10.2400
1906	04/18/06	27,600	36.00	814.40	297.55	778.40	0.13	814.53	816.95	-2.42	5.8564
1943	04/12/43	28,200	38.16	816.58	296.00	778.42	1.00	817.58	817.25	0.33	0.1089
1967	04/04/67	28,200	37.50	815.85	295.70	778.35	1.19	817.04	817.25	-0.21	0.0441
1920	03/29/20	30,200	41.00	819.40	297.55	778.40	0.13	819.53	818.20	1.33	1.7689
1907	04/07/07	30,400	39.95	818.35	297.55	778.40	0.13	818.48	818.40	0.08	0.0064
1972	04/18/72	30,800	38.73	817.08	295.70	778.35	1.18	818.26	818.50	-0.24	0.0576
1986	04/02/86	31,900	37.00	817.00	297.65	780.00	0.00	817.00	818.95	-1.95	3.8025
1984	04/02/84	32,300	37.06	817.06	297.65	780.00	0.00	817.06	819.15	-2.09	4.3681
1904	04/27/04	33,000	40.65	819.05	297.55	778.40	0.13	819.18	819.45	-0.27	0.0729
1947	04/22/47	34,200	40.71	819.13	296.00	778.42	1.00	820.13	819.90	0.23	0.0529
1948	04/16/48	34,200	41.68	820.10	296.00	778.42	1.00	821.10	819.90	1.20	1.4400
1974	04/19/74	34,300	40.25	818.60	295.70	778.35	1.18	819.78	819.95	-0.17	0.0289
1989	04/12/89	37,900	44.37	823.37	297.65	779.00	0.00	823.37	821.20	2.17	4 7089
1883	04/26/83	38,600	42.20	822.10	297.55	779.90	0.14	822.24	821.45	0.79	0.6241
1975	04/23/75	42,200	43.30	821.65	295.70	778.35	1.20	822.85	822.45	0.40	0.1600
										$\Sigma(X-M)^2$	= 63.34
									Variance	$= SD^2$	= 2.75
								Standard	Deviation	= SD	= 1.66
1965	04/17/65	52,000	44.92	823.27	296.00	778.35	1.24	824.51	824.65	-0.14	0.0196
1893	04/24/93	53,300	45.50	825.40	297.55	779.90	0.34	825.74	824.95	0.79	0.6241
1969	04/16/69	53,500	45.69	824.04	295.70	778.35	1.45	825.49	825.00	0.49	0.2401
1950	05/12/50	54,000	45.61	824.03	296.00	778.42	1.28	825.31	825.05	0.26	0.0676
1978	04/11/78	54,200	45.73	824.08	295.70	778.35	1.47	825.55	825.10	0.45	0.2025
1966	04/04/66	55,000	45.55	823.90	295.70	778.35	1.50	825.40	825.25	0.15	0.0225
1882	04/18/82	75,000	48.00	827.90	297.55	779.90	0 40	828.30	828.35	-0.05	0.0025
1979	04/26/79	78,400	48.81	827.16	295.70	778.35	1.85	829.01	828.80	0.21	0.0441
1897	04/10/97	85,000	50.20	830.10	297.55	779.90	0.36	830.46	829.60	0.86	0.7396
										$\Sigma(X-M)^2$	= 1.96
									Variance	$= SD^2$	= 0.25
								Standard	Deviation	= SD	= 0 50

Project Sizing Simulation Results. The simulation (true) exceedence frequencies for alternative top of levee heights are summarized in Table 5. These frequencies were plotted versus the levee top heights and the curve, shown on Plate 2, was developed to estimate the levee top height that would have a simulation exceedence frequency of 1 percent in any given year. A levee top height with a simulation exceedence frequency of 1 percent is the tentatively proposed FEMA requirement for a project developed using risk and uncertainty. As can be seen in Plate 2, a levee top height of 831.5 has an exceedence frequency of 1 percent.

Table 5 - Levee Top Height Exceedence Frequencies

Alternative Levee Top Height	Simulation (True) Exceedence Frequency in Percent
829.0	2.10
830.0	1.64
831.0	1.18
832.0	0.90
833.0	0.82
834.0	0.66
835.0	0.34
831.5	1.00

Project Reliability Simulation Results. The project reliability results for the 1 percent (100-year) event are summarized to a limited degree in the last row of Table 6 and are extensively summarized in Tables 7 and 8. The far right column of Tables 7 and 8 contains the reliability results based on the adopted values for the Grand Forks project. The remaining columns present results for a sensitivity analysis that is described later.

Levee Requirements. A summary of simulation (true) exceedence and reliability for levees with top heights based on old and new criteria requirements is shown in Table 6.

Table 6 - SUMMARY OF NEW CRITERIA FOR LEVEES - GRAND FORKS		
	ITEM	ELEVATION /PROBABILITY
CONDITION	1. 100-yr flood, w/ GF project, w/ EGF floodway, w/ expected probability	831.8 FEET
	2. 100-yr flood, w/ GF project, w/ EGF floodway, w/o expected probability	831.4 FEET
	3. 1.0% chance of being exceeded in any given year - Previously proposed FEMA requirement	831.5 FEET
LEVEE HEIGHT	4. Freeboard criteria, w/ GF project, w/ EGF floodway, w/ expected probability + 3.0 ft	834.8 FEET
	5. Freeboard criteria, w/ GF project, w/ EGF floodway, w/o expected probability + 3.0 ft	834.4 FEET
	6. Optimized using risk and uncertainty	NA
	7. Previously proposed FEMA Criteria	831.5 FEET
RISKS-DURING ANY GIVEN YEAR	8. True probability of overtopping old Corps criteria design during any given year using levee height shown on line 4.	0.0042
	9. True probability of overtopping during any given year using the levee height shown on line 5.	0.0056
	10. True probability of overtopping optimized design during any given year using levee height shown on line 6.	NA
RELIABILITY DURING .01 EVENT (100YR-FLOOD)	11. Percent chance of exceedence for 0.01 event for old Corps criteria design using levee height shown on line 4.	7.0 PERCENT
	12. Percent chance of exceedence for 0.01 event for levee height shown on line 5.	9.2 PERCENT
	13. Percent chance of exceedence for 0.01 event for optimized design using levee height shown on line 6.	NA
	14. Percent chance of exceedence for 0.01 event for levee at previously proposed FEMA Criteria.	47.2 PERCENT

References:
1. Proceedings of a Hydrology and Hydraulics Workshop on Riverine Levee.Freeboard, 27-29 August 1991, Monticello, Minnesota.
2. Draft EC, 1 August 1992. Risk Analysis Framework for Evaluation of Hydrology/Hydraulics and Economics in Flood Damage Reduction Studies.
3. Draft EC, November 1993. Risk-Based Analysis for Sizing and Performance Evaluation of Flood Damage Reduction Projects.

Sensitivity. Tables 7 and 8 below summarize the results of the reliability analysis for the 1-percent event. These tables also contain columns which illustrate the sensitivity of the results to the number of iterations, the rating curve standard deviation of error and the number of years of record used in the analysis. Columns 6 and 7 of the tables contain reliability information for the adopted values for the Grand Forks project for 8000 and 5000 iterations respectively. This information illustrates that 5000 iterations are adequate because the elevations and frequencies change only an insignificant amount with 8000 iterations. Columns 2, 3, and 7 illustrate the sensitivity of the results to the number of years of record. Columns 2 uses a period of record (N value) of 100,000 years which simulates a discharge frequency curve with an extremely long period of record and; therefore, confidence limits that approach the computed discharge frequency. This essentially eliminates the uncertainty in the risk analysis due to discharge and allows the determination of the top elevation of levee resulting from the uncertainty in stage. Column 3 uses a period of record of 10,000 years. Column 7 uses the actual period of record of 112 years for the U.S.G.S. gage which is considered a long period of record. As can be seen, the elevations and probabilities change a significant amount when the period of record is reduced to the actual period of record. For instance, the 95 percent reliability elevation in Table 7 changes from 832.3 to 835.2, an increase of 2.9 feet. Conversely, the reliability for an elevation of 831.5 in Table 8 decreases from 57 or 58 percent to 52 percent. Columns 4, 5 and 7 illustrate the sensitivity of the results to the uncertainty in the stage-discharge rating curve as measured by the standard deviation of the curve. The 95 percent reliability elevation in Table 7 with the adopted standard deviation of 0.50 feet is 835.18. This decreases only 0.16 feet to 835.02 with a standard deviation of 0.01 feet and increases only 0.41 feet with a standard deviation of 1.00 feet. Conversely, the reliability for an elevation of 831.5 in Table 8 increases only 0.1 percent for a standard deviation of 0.01 feet and decreases only 1.2 percent for a standard deviation of 1.00 feet. In summary, the reliability results in Tables 7 and 8 show that reliability is much more dependent on the period of record than on the uncertainty in the stage-discharge rating curve.

Table 7 - Sensitivity of Hydrologic and Hydraulics Project Reliability for Grand Forks, North Dakota						
Percent	P event=.01 N=100,000 SDrc=0.50 I=5000	P event=.01 N=10,000 SDrc=0.50 I=5000	P event=.01 N=112 SDrc=1.00 I=5000	P event=.01 N=112 SDrc=.01 I=5000	P event=.01 N=112 SDrc= 0.50 I=8000	Adopted Values Pevent=.01 N=112 SDrc=0.50 I=5000
80 Percent	831.82	831.87	833.46	833.32	833.31	833.31
85 Percent	831.92	831.97	833.92	833.72	833.75	833.73
90 Percent	832.04	832.11	834.53	834.13	834.25	834.28
91 Percent	832.07	832.14	834.70	834.31	834.39	834.43
92 Percent	832.11	832.18	834.87	834.48	834.55	834.62
93 Percent	832.14	832.23	835.09	834.66	834.72	834.81
94 Percent	832.19	832.26	835.33	834.84	834.94	834.97
95 Percent	832.23	832.31	835.59	835.02	835.21	835.18
96 Percent	832.29	832.37	835.87	835.49	835.56	835.54
97 Percent	832.35	832.44	836.25	835.97	835.97	835.94
98 Percent	832.44	832.53	836.70	836.44	836.55	836.52
99 Percent	832.56	832.65	837.38	836.90	837.10	837.14
100 Percent	833.27	833.65	839.94	837.61	838.58	838.42

P event = probability of flood event (decimal).
N = number of years of record. Values greater than 112-years used for sensitivity analysis only.
SDrc = standard deviation of elevation discharge rating curve data points above 50,000 cfs.
I = number of iterations for Latin Hypercube simulation.

Table 8 - Sensitivity of Hydrologic and Hydraulics Project Reliability for Grand Forks, North Dakota						
FEMA Requirement						
Elevation in Feet with one percent chance of being exceeded in any given year - Simulation Exceedence	P event=.01 N=100,000 SDrc=0.50 I=5000	P event=.01 N=10,000 SDrc=0.50 I=5000	P event=.01 N=112 SDrc=1.00 I=5000	P event=.01 N=112 SDrc=.01 I=5000	P event=.01 N = 112 SDrc=0.50 I=8000	Adopted Values Pevent=.01 N=112 SDrc=0.50 I=5000
EL 831.5	57.9 Percent	57.3 Percent	50.6 Percent	51.9 Percent	51.4 Percent	51.8Percent

P event = probability of flood event (decimal).
N = number of years of record. Values greater than 112-years used for sensitivity analysis only.
SDrc = standard deviation of elevation discharge rating curve data points above 50,000 cfs.
I = number of iterations for Latin Hypercube simulation.

Crookston

General. The risk analysis for the Red Lake River at Crookston, Minnesota, was very similar to that for Grand Forks. The main difference was the uncertainty in the stage-discharge relationship and only that will be discussed here. The Red Lake River at Crookston has a significant history of ice-jam flooding. The following discusses how this was addressed in the risk-based analysis.

As shown on Plate 3, which is the adopted stage-discharge rating curve at the gage in Crookston, the stages are only impacted by ice for lower discharges. The stage uncertainty had to be analyzed for both unobstructed open flow conditions and for ice impacted conditions. Therefore, it was decided that a normal distribution would be used for the open flow conditions stage uncertainty and a lognormal distribution would be used for the ice impacted stage uncertainty.

Existing conditions computed water surface elevations are based on the HEC-2 model calibrated to unobstructed open flow conditions. The adopted stage-discharge rating curve at the gage shown on Plate 3 is based on these computed water surface elevations. The standard deviation for open flow conditions is computed in Table 2. The adopted stages shown in this table were obtained from this adopted stage-discharge rating curve. As shown in the table, the standard deviation for open flow conditions is 0.83 feet. The 2- and 98-percent confidence limits

shown on Plate 3 for discharges greater than about 23,000 cfs are based on plus or minus two standard deviations of 0.83 feet. For discharges less than 23,000 cfs, the 2-percent lower confidence limit was continued at open flow two standard deviations below the adopted rating curve. This curve encompassed all events lower than the adopted rating curve. Then another curve was drawn above the adopted rating curve that encompassed all the ice impacted stages higher than the curve. This curve was assumed to be the 98-percent confidence limit. The resulting stages at six discharges are shown in Table 9. Lognormal parameters that fit these distributions were determined and are shown in Table 10. In order to get the distributions to match it was necessary to determine a 0% stage - the stage that has a 100% chance of being exceeded, also called the shift. This stage and the other parameters were determined by trial and error until the resulting distribution had the correct chance of being exceeded at the 2% and 98% stages in Table 9. In determining the lognormal parameters the HEC-2 computed rating curve values were considered the most likely (mode) values rather than the means.

Distributions for the ice impacted portion of the rating curve tried were normal, beta, triangular and lognormal. The lognormal gave the best fit. The normal distribution didn't work since the distribution is skewed by the impact of ice. The triangular distribution didn't fit as well since it seems to underestimate the clustering of points near the rating curve and doesn't have the long tails that represent extreme possibilities. The beta distribution is not commonly used and is harder to fit to the historic data since it's more trial and error than the lognormal. The log normal distribution was fit at 1000, 3000, 5000, 10000, 15000 and 20000 cfs.

After the stage-discharge rating curve uncertainty analysis had been completed, EM 1110-2-1619 was received. On page 5-3 it recommends using a gamma distribution for rating curve uncertainty. As a check the gamma distribution of one discharge, 15,000 cfs, was determined and compared to the lognormal distribution. For the gamma distribution there are 3 unknowns: the shift, alpha (or k) and beta (or b). A lotus 1-2-3 spreadsheet was used to find the 3 unknowns. The Lotus spreadsheet did not have a @gamma function so a @chidist function was used. The conversion from a chi-square to a gamma distribution is shown on page 294 of Probability, Statistics and Decision for Civil Engineers by Benjamin and Cornell. The 3 unknowns were varied until the resulting distribution matched the 2%, 98% and mode of the data. Again the computed HEC-2 rating curve elevation was considered the most likely (mode) value rather than the mean value. For the gamma distribution the mode is equal to beta(alpha-1). Plate 4 is the spreadsheet used to find the gamma parameters. Plates 5 compares the gamma and the log normal distributions for 15,000 cfs. The graphs plot on top of each other - the log normal and gamma results are basically the same.

The lognormal distributions developed for the various discharges less than 23,000 cfs and incorporated into the Hydrologic Engineering Center @RISK spreadsheet template. The equations in the spreadsheet used the lognormal distributions for discharges less than 23,000 cfs and normal distributions with a standard deviation of 0.83 feet above this discharge. A vertical lookup table was added to the spreadsheet so that the appropriate variables were used in the lognormal distributions.

Table 9 - Crookston Stages			
Discharge	2% Stage	Rating Curve Stage	98% Stage
1,000 cfs	3.4	5.0	9.5
3,000 cfs	6.6	8.2	19.1
5,000 cfs	9.6	11.2	21.0
10,000 cfs	16.0	17.6	23.5
15,000 cfs	20.0	21.6	25.3
20,000 cfs	22.6	24.2	26.7

Table 10 - Crookston Log Normal Parameters			
Discharge	0% Stage	LN (Mean Stage)	LN Std Deviation
1,000 cfs	1.349	1.4082	0.3365
3,000 cfs	5.453	1.3753	0.6040
5,000 cfs	8.398	1.3589	0.5731
10,000 cfs	14.376	1.3479	0.4210
15,000 cfs	17.450	1.4983	0.2742
20,000 cfs	17.646	1.9017	0.1471

Table 11- Determination of Standard Deviation for Open Flow Conditions

Station RED LAKE RIVER AT CROOKSTON, MN Id - 05079000
State MN Drainage Area 5280 Hydrologic Unit 9020303
County 119 Years 1901 - PRESENT
Latitude 47:46:32 Gage Datum 832.72
Longitude 096:36:33

Year	Date	Discharge in cfs	X Observed Stage in Feet	M Adopted Stage in Feet	(X-M) Observed minus Adopted	$(X-M)^2$
1902	05/21/02	5,170	10.00	11.44	-1.44	2.0736
1904	04/24/04	13,700	20.42	20.64	-0.22	0.0484
1905	05/13/05	8,730	14.50	16.15	-1.65	2.7225
1906	04/15/06	14,600	21.00	21.28	-0.28	0.0784
1907	04/04/07	6,330	12.04	13.24	-1.20	1.4400
1908	04/10/08	10,700	17.00	18.50	-1.50	2.2500
1909	07/21/09	3,680	8.77	9.13	-0.36	0.1296
1911	06/10/11	3,620	8.45	9.04	-0.59	0.3481
1914	06/12/14	2,630	7.40	7.51	-0.11	0.0121
1915	06/29/15	7,860	14.25	15.12	-0.87	0.7569
1916	04/17/16	15,900	21.80	22.14	-0.34	0.1156
1918	04/02/18	1,950	6.50	6.45	+0.05	0.0025
1919	07/05/19	14,900	21.10	21.50	-0.40	0.1600
1922	05/13/22	6,910	13.00	13.99	-0.99	0.9801
1924	04/23/24	1,140	5.20	5.20	0.00	0.0000
1925	06/09/25	7,300	13.50	14.45	-0.95	0.9025
1926	03/24/26	6,500	12.30	13.50	-1.20	1.4400
1927	04/13/27	7,700	14.00	14.93	-0.93	0.8649
1930	05/13/30	4,770	10.30	10.82	-0.52	0.2704
1932	04/09/32	4,390	9.78	10.23	-0.45	0.2025
1934	04/08/34	1,490	6.89	5.74	+1.15	1.3225
1938	05/10/38	5,910	12.62	12.59	+0.03	0.0009
1939	04/24/39	3,050	8.92	8.16	+0.76	0.5776
1943	04/08/43	9,420	16.88	16.98	-0.10	0.0100
1944	08/11/44	5,770	12.20	12.37	-0.17	0.0289
1945	03/28/45	9,130	15.96	16.63	-0.67	0.4489
1947	06/12/47	12,400	18.08	19.71	-1.63	2.6569
1949	06/02/49	10,700	17.43	18.50	-1.07	1.1449
1950	05/07/50	27,400	25.70	26.87	-1.17	1.3689
1951	04/07/51	12,600	19.00	19.86	-0.86	0.7396
1952	04/11/52	6,320	12.65	13.22	-0.57	0.3249
1954	04/12/54	5,330	11.37	11.69	-0.32	0.1024
1955	04/08/55	12,400	18.30	19.71	-1.41	1.9881
1956	04/20/56	14,000	19.78	20.86	-1.08	1.1664
1957	06/29/57	11,800	18.10	19.28	-1.18	1.3924
1958	07/07/58	3,370	8.62	8.65	-0.03	0.0009
1959	04/05/59	5,630	11.72	12.15	-0.43	0.1849
1961	03/27/61	1,450	5.67	5.68	-0.01	0.0001
1962	06/11/62	16,700	21.90	22.53	-0.63	0.3969
1963	04/09/63	6,820	13.25	13.88	-0.63	0.3969
1966	04/03/66	21,500	24.41	24.87	-0.46	0.2116
1967	04/01/67	19,300	23.49	23.80	-0.31	0.0961
1968	07/19/68	11,100	17.17	18.78	-1.61	2.5921
1969	04/12/69	28,400	27.33	27.15	+0.18	0.0324
1971	04/10/71	15,300	20.74	21.78	-1.04	1.0816
1973	09/26/73	4,960	10.86	11.12	-0.26	0.0676
1975	04/18/75	15,600	21.97	22.00	-0.03	0.0009
1976	04/03/76	12,500	19.45	19.78	-0.33	0.1089
1977	05/20/77	3,440	8.66	8.76	-0.10	0.0100
1978	04/07/78	18,100	23.11	23.22	-0.11	0.0121
1979	04/26/79	21,900	24.99	25.06	-0.07	0.0049
1981	06/29/81	7,120	13.56	14.24	-0.68	0.4624
1984	06/10/84	14,400	20.71	21.14	-0.43	0.1849
1985	08/19/85	9,580	16.38	17.17	-0.79	0.6241
1991	06/13/91	1,300	6.99	5.45	+1.54	2.3716

Sum = 36.9123
Standard Deviation Squared (Variance) = 0.6836
Standard Deviation = 0.8268

Potential Impacts of New Guidance

General. As mentioned at the start of this paper, the work presented was done prior to the development of the Flood Damage Analysis (HEC-FDA) program, the record flood of 1997, and the 10 April 1997 Guidance on Levee Certification for the National Flood Insurance Program memo from CECW-P/CECW-E. Some of these changes could impact the results.

HEC-FDA. It is expected that this program could be used for the Grand Forks analysis with no impact on the results but could not be used for Crookston. The program allows variation in the standard deviation of the uncertainty in the stage-discharge relationship. This was needed for the Grand Forks study and required the modification of the original HEC spreadsheet. The HEC-FDA program would make this analysis more straight forward. The Crookston analysis used different uncertainty distributions for portions of the stage-discharge rating curve. The lower portion used a lognormal distribution due to ice impacts and a normal distribution for the upper portion, which is not ice impacted. The HEC @risk spreadsheet was modified to handle this but the HEC-FDA program is not designed for this and would likely be too difficult to modify by the field. Therefore, we would not use the HEC-FDA program for any future Crookston-like analysis.

Flood of 1997. The 1997 flood was a new record for both Grand Forks and Crookston. The impact of the flood on the risk analysis at Grand Forks will be determined but no results are available now. The Feasibility Study for Crookston has been approved and the impact of the 1997 flood will not be quantified. Analysis to date indicates the discharge-frequency curve at Grand Forks will be significantly impacted by the 1997 flood. While the measured peak stage and discharge at Grand Forks was fairly close to the previous stage-discharge rating curve, it appears the uncertainty we had used, a standard deviation of 0.50 ft, may be increased. The damages sustained could have an impact on the previous stage-damage curve. It appears the damages were higher than anticipated, however, many buildings were destroyed and won't be replaced and therefore won't contribute to the possible future damages. The net result of this on the stage-damage curve is not known.

New Levee Certification Guidance. The guidance presented in the 10 April 1997 memo from CECW-P/CEWC-E concerns how to certify a levee for FEMA when risk and uncertainty analysis is used. The method proposed is a significant improvement over the method previously proposed by FEMA. FEMA's past proposal was that the levee elevation had to have a true probability of overtopping of 1%. Line 3 of Table 6 showed that for Grand Forks this resulted in a top of levee of 831.5. Line 14 of that table shows this elevation has a 47.2% chance of being overtopped during a 1% flood event. This was far too high a probability to allow our district to certify the levee as providing flood protection from the regulatory flood. This had the potential of confusing the locals when two federal agencies couldn't agree on what levee height was required for certification. The 10 April 1997 policy is summarized in Plate 6. Applying this to the Table 6 data shows that either the 100-yr flood with or without expected probability levee heights, lines 1 and 2, could be certified since they each have less than a 10% chance of being exceeded during a 1% event, lines 11 and 12.

Geotechnical Reliability of Levees

by

Thomas F. Wolff[1]

ABSTRACT

The Corps of Engineers now performs cost-benefit analyses in a probabilistic framework. In support of such studies, geotechnical engineers must quantify the reliability of levees and other earth structures. Resource constraints for planning-level studies require that methods used permit the use of existing computer programs, be easy to implement in practice, and be useful where data are limited.

This paper reviews past Corps' guidance for assessing the geotechnical reliability of existing levees and reports the results of a research study to develop an improved and more comprehensive approach. In the developed methodology, several modes of levee performance are analyzed using a probabilistic capacity-demand model. By replicate analyses at different water heights, a conditional-probability of failure function for each mode can be developed as a function of flood water elevation. These in turn can be combined to develop a composite probability-of-failure function. Examples are provided for slope stability and underseepage, and other modes are discussed. The change in reliability for a levee subjected to increasing water heights is illustrated.

Based on the research, a new Engineering Circular (EC) is under development to implement the methodology in the Corps. However, there are still a number of known limitations for which additional research and development appear warranted. These are discussed.

INTRODUCTION

When the Corps of Engineers proposes construction of new levees or improvement of existing levees (typically raising the height), economic studies are required to assess the benefits and costs. Where an existing levee is present, the project benefits accrue from the increase in the degree of protection. Economic assessment of the improvement in turn requires an engineering determination of the probable level of protection afforded by the existing levee.

A research project by the author (Wolff, 1994) at Michigan State University involved developing and testing procedures that can be used by geotechnical engineers to assign conditional probabilities of failure for existing levees as functions of flood water elevation. Such functions may be used by economists to estimate benefits from proposed levee improvements. More recently, the author, under contract with Shannon and Wilson, Inc., to the Corps, prepared

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a draft Engineering Circular (EC) titled *Risk-Based Analysis in Geotechnical Engineering for Support of Planning Studies* (U.S. Army, 1997), which is in press at the time of this conference. It includes two appendices; Appendix A is entitled *An Overview of Probabilistic Analysis for Geotechnical Engineering Problems* (Wolff and Shannon and Wilson, 1997). Appendix B is the full text of the research report (Wolff, 1994) discussed above.

The new EC and its two appendices provide the current guidance for reliability assessment of levees in support of planning studies. This paper summarizes the recommended methodology, the research leading to it, and some remaining shortcomings that warrant further study.

EARLIER PRACTICE FOR EVALATING EXISTING LEVEES

Prior to 1991, existing levees that had not been designed or constructed to Corps' standards were often considered to be non-existent in economic analysis or to afford protection to some low and rather arbitrary elevation. (ETL 1110-2-328, U.S. Army, 1992) These assumptions are no longer permitted; in guidance issued in 1991-92, an existing levee is considered to afford protection with some associated probability.

Probable Failure and Non-Failure Points. Policy Guidance Letter No. 26 (U.S. Army, 1991) and draft ETL 1110-2-328, *Stability Evaluation of Existing Levees for Benefit Determination* (U.S. Army, 1992) provided simplistic quantitative guidance for assessing geotechnical reliability of existing levees. PGL No. 26 introduced the concept of levee reliability as a function of floodwater elevation, and introduced the concepts of *probable failure point* and *probable non-failure point*:

> *...commands...(i.e. Corps district and division offices) making reliability determinations should gather information to enable them to identify two points... The highest vertical elevation on the levee such that it is highly likely that the levee would not fail if the water surface would reach this level... shall be referred to as the Probable Non-Failure Point (PNP)... The lowest vertical elevation on the levee such that it is highly likely that the levee would fail... shall be referred to as the Probable Failure Point (PFP).. As used here, "highly likely" means 85+ percent confidence...*

PGL No. 26 went on to state:

> *If the form of the probability distribution is not known, a linear relationship as shown in the enclosed example, is an acceptable approach for calculating the benefits associated with the existing levees.*

PGL No. 26 took the probability of failure to increase linearly with flood water height from 0.15 at the PNP to 0.85 at the PFP. This assumption would permit an economist, in the absence of any further engineering analysis, to quantify reliability as a linear function. The

engineer needs only, by some means, to identify flood water elevations for which the levee is considered 15 and 85 percent reliable.

Shape of Reliability Function. The assumption of linearity is expedient, and is the least-biased assumption where only two points are known and no other information is present. However, the assumption of linearity may or may not be acceptable once some additional information *is* known. One of the objectives of the research was to determine what is in fact a reasonable function shape based on the results of some engineering analyses for typical levee cross sections and typical parameter values.

The Template Method. In ETL 1110-2-328, the *template method* was presented for determining PNP and the PFP. In this method, stated to be applicable only to levee cross-sections that have met other requirements of geometry, seepage, and slope stability, two idealized cross-sections, considered to meet desirable and minimal design standards, are drawn and fit within the cross-section of the existing levee. When the templates are matched to the existing cross-section at the toe points, the tops of these two templates are taken to be the PNP and PFP, respectively.

The template method for determination of the PNP for a "typical" clay levee by the ETL is illustrated in Figure 1. For a typical sand levee, the template crown would be widened to 12' and the side slopes flattened to 1v on 4h. The template method for determination of the PFP for a typical clay levee is shown in Figure 2. For a typical sand levee, the template crown would be widened to 8' and the side slopes flattened to 1v on 3h.

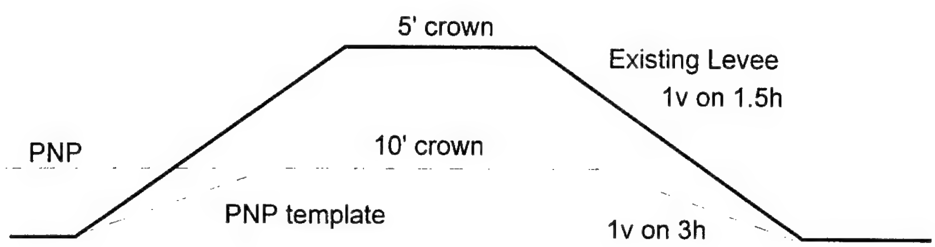

Figure 1. Template for PNP - clay levee

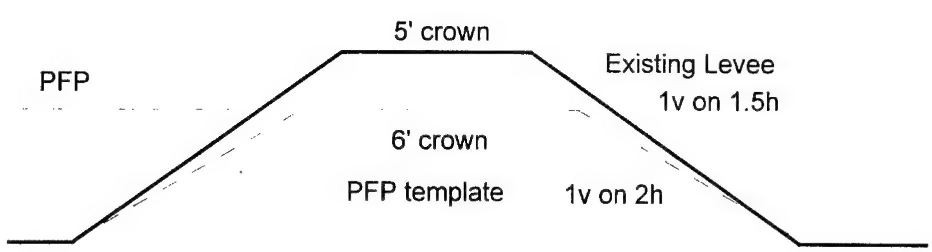

Figure 2. Template for PFP - clay levee

Implied Assumptions Regarding Slope Stability. When the definitions of the PNP and PFP are considered in conjunction with the template method, two significant assumptions are implied:

1) The PNP template, defined to be "*representative of a stable levee section for the soils involved and having an appropriate crest width and side slopes*", is implied to have a reliability of 85% and a probability of failure 15%.

2) The PFP template, defined to be a reduced section at which a levee would be stable for reduced periods of time, is implied to have a reliability of 15% and a probability of failure of 85%.

Reasonableness of these Assumptions. The Pr(f) = 0.15 associated with the elevation of the PNP is unreasonably high. Given this probability value, about 1 in 6 new levees built to 1V on 3H slopes would be expected to fail. Various studies (e.g. Wolff, 1985; Shannon and Wilson, 1994, Vrouwenvelder, 1987) indicate that dams, levees and dikes designed to Corps criteria or Dutch criteria would be expected to have probabilities of failure on the order of 10^{-3}, 10^{-4}, and even lower. Hence, the conditional probability of failure associated with the PNP elevation determined from the template method should be expected to be in the range of perhaps 0.001 to 0.0001, not 0.15.

The Pr(f) = 0.85 associated with the elevation of the PFP also appears to be high in the context of experience, although probably not so much as for the PNP template. If an engineer judged this section equally likely to fail as to stand up, which seams to be a reasonable assumption, the section would correspond to a $Pr_f = 0.50$ rather than 0.85.

As slope stability has a well-developed mathematical basis, and is relatable to measurable soil properties, it is a candidate for inclusion in a probabilistic levee reliability methodology.

Performance modes other than slope stability. The template method was the only procedure sufficiently quantified to permit assigning probability values, and it presumably relates primarily to slope stability. Other performance modes were required to be considered, but no quantitative methods to do so were presented. Other potential performance modes include:

1) Safety against **overtopping**, including flood duration and ability of levee materials to endure that duration.

2) Safety against **underseepage** with associated sand boils and piping. This is a well-recognized hazard not even considered in the template method. For underseepage, safety is essentially independent of crown width and slopes; but is highly dependent on foundation stratigraphy.

3) Safety against **through-seepage** and associated internal erosion, piping, or surface erosion of the landside slope (cited in PGL 26). This mode *is* related to the levee

template and material; however equating of the PNP and PFP levels to Pr(f) = 0.15 and 0.85 does not directly follow from any through-seepage considerations.

4) Safety against **surface erosion** of slopes and crest **resulting from rainfall** (cited in PGL 26). This is primarily related to slope, material type, and vegetative cover. The PNP and PFP are not directly related to these factors.

5) Safety against **surface erosion due to current and wave attack on the riverside slope** (not specifically cited in PGL 26). During high stages when the upper part of the riverside slope is exposed to attack, current velocities are higher, and fetch distances are longer.

6) **Flood duration.** Some levees may be subjected to significant water heights for many months. When this occurs, the phreatic surface within the levee will rise, increasing pore pressures and increasing the risk of failure due to through-seepage, underseepage and slope stability. This is acknowledged in a rudimentary way in the draft ETL which reduces the crest width when the levee is exposed to flood heights for only a limited time.

7) **Geometry beyond the levee toe**, such as distance to the river, location and depth of borrow areas, and presence or absence of vegetation and tree cover between the levee. This is not considered in the template method. These conditions may impact slope stability, underseepage, current velocities, and wave fetch distance.

8) **Other items** from the preliminary inspection, such as "*vegetation ... animal burrows, man-made excavation through surface impervious layers, ...cracks, toe-undercutting, slides, and ...soil creep* " are to be considered in developing the function, but no guidance is provided as to how to do so.

THE CONDITIONAL PROBABILITY OF FAILURE FUNCTION

The research (Wolff, 1994) and the forthcoming EC take the approach of constructing a conditional probability of failure function dependent on flood water elevation. A number of performance modes are considered, a separate function is developed relating the conditional probability of failure for each mode to flood water elevation, and these are then combined.

The conditional probability of failure can be written as:

$$\Pr(f) = \Pr(\text{failure} \mid \text{FWE}) = f(\text{FWE}, X_1, X_2, \ldots X_n) \qquad (1)$$

In the above expression, the symbol "|" is read *given* and the variable FWE is the flood water elevation. The random variables X_1 through X_n denote relevant parameters such as soil strength, permeability, top stratum thickness, etc. Equation 1 can be restated as follows: "The probability of failure, given the flood water elevation, is a function of the flood water elevation and other random variables."

Two extreme values of the function can be readily estimated by engineering judgment. For flood water at the same level as the landside toe (base elevation) of the levee, $P_f = 0$; for flood water at or near the levee crown (top elevation), $P_f \rightarrow 1.00$. The question of primary interest, however, is the shape of the function between these extremes. Quantifying this shape is the focus herein; how reliable might the levee be for, say, a ten or twenty-year flood event that reaches half or three-quarters the height of the levee?

Reliability (R) is defined as:

$$R = 1 - P_f \qquad (2)$$

hence, for any flood water elevation, the probability of failure and reliability must sum to unity. For flood water part way up a levee, R could be near zero or near unity, depending on factors such as levee geometry, soil strength and permeability, foundation stratigraphy, etc. Five possible shapes of the R = f(FWE) function are illustrated in Figure 3. For a "good" levee, the probability of failure may remain low and the reliability remain high until the flood water elevation is rather high. In contrast, a "poor" levee may experience greatly reduced reliability when subjected to even a small flood head. It is hypothesized that some real levees may follow the highlighted intermediate curve, which is similar in shape to the "good" case for small floods, but reverses to approach the "poor" case for floods of significant height. Finally, a straight line function is shown, similar to the previously-assumed linear relation between reliability and flood height.

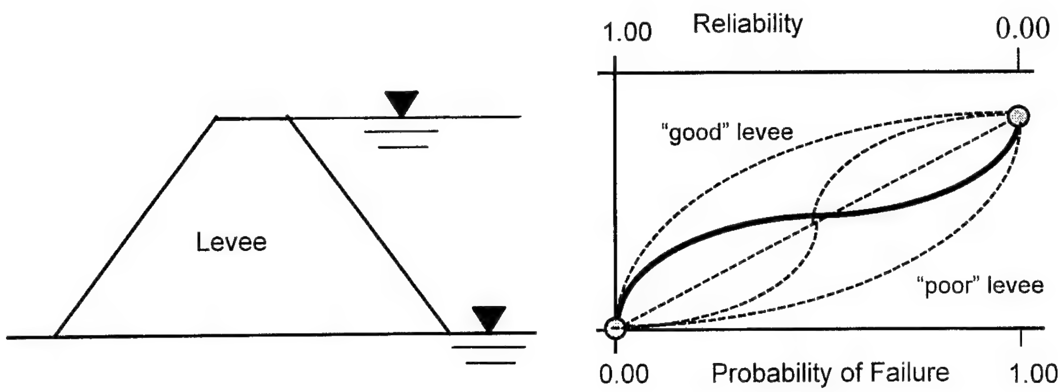

Figure 3. Possible Reliability vs. Flood Water Elevation Functions for Existing Levees

RELATED RELIABILITY ANALYSIS PROCEDURES USED BY THE CORPS

Quantifying geotechnical reliability for planning studies poses a challenge. Many published techniques are too complex for routine practice, require more data than will be available, or require specialized computer programs. Given these constraints, the selected probabilistic methods must be based on some combination of limited testing and experience, and

existing procedures and computer programs (e.g. for slope stability and seepage analysis) must be used as much as feasible.

The procedures for constructing conditional Pr(f) functions are built on earlier-developed methodology for navigation structures. Several studies have been made to develop procedures (Wolff and Wang, 1992a, 1992b; Shannon and Wilson and Wolff, 1994) and to promulgate guidance (U.S. Army, 1992a). In general, these methods are based on expressing the uncertainty in structural performance as a function of the uncertainty in the values of the variables in an associated performance model, such as a slope stability or underseepage analysis.

GENERAL METHODOLOGY

The term *probability of unsatisfactory performance*, Pr(U) is often used in Corps reliability guidance (U.S. Army, 1992a,b) in lieu of the more common *probability of failure* Pr(f), to reflect the fact that remedial measures are expected to be taken before a catastrophic failure condition becomes imminent. However, for existing levees, the latter term may be accurate. In economic risk assessments, Pr(U) or Pr(f) values for several performance modes are combined with economic consequences (flooding, loss of service, etc.) to determine probabilistic benefits and costs. Ideally, one would like to obtain "absolute" values for Pr(U) or Pr(f). However, several factors restrict the task to calculating comparative measures. These include limited data, lack of knowledge regarding the shape of probability distributions, and the use of approximations such as first-order second-moment (FOSM) methods, which facilitate the use of existing computer programs.

Determining the Reliability Index. The basic scheme for reliability analysis is summarized in Corps' guidance (U.S. Army, 1992a,b) and is only briefly reviewed here. Comparative reliability is measured by the *reliability index* β. As illustrated in Figure 4, β is the number of standard deviations by which the expected value of the *performance function* exceeds the *limit state.* The natural log of the factor of safety, ln FS, is taken as the performance function and the condition ln FS = 0 is taken as the limit state. β incorporates the information inherent in the factor of safety, but additionally provides a measure of the relative certainty or uncertainty regarding parameter values. Calculating β involves five steps:

1) Identifying a performance function and limit state, typically ln FS = 0.
2) Identifying the *random variables* contributing uncertainty.
3) Characterizing the random variables by of their expected values E[X], coefficients of variation V_x and, where necessary, their correlation coefficients $\rho_{X,Y}$.
4) Determining the expected value and standard deviation of the performance function using the Taylor's Series Finite Difference (TSFD) method.
5) Evaluating β from the results of step 4.

For step 1, the safety factor against slope failure is commonly determined using the UTEXAS computer program (Edris and Wright, 1987). For underseepage, the factor of safety is

taken as the ratio of the critical gradient i_c to the exit gradient i_o at the landside toe (U.S. Army, 1956). Exit gradients may be calculated by hand solution, spreadsheet, or with the program LEVEEMSU (Wolff, 1989). For other performance modes, widely-accepted performance functions and limit may not be available to the same extent as for slope stability and underseepage; additional research may be required.

For step 2, random variables for slope stability are typically the shear strength parameters c and ϕ. For underseepage analysis they are typically the horizontal permeability of pervious substratum foundation materials k_f, the vertical permeability of semipervious top blanket materials $k_{b,}$, and the thickness of the top blanket at the landside levee toe, z.

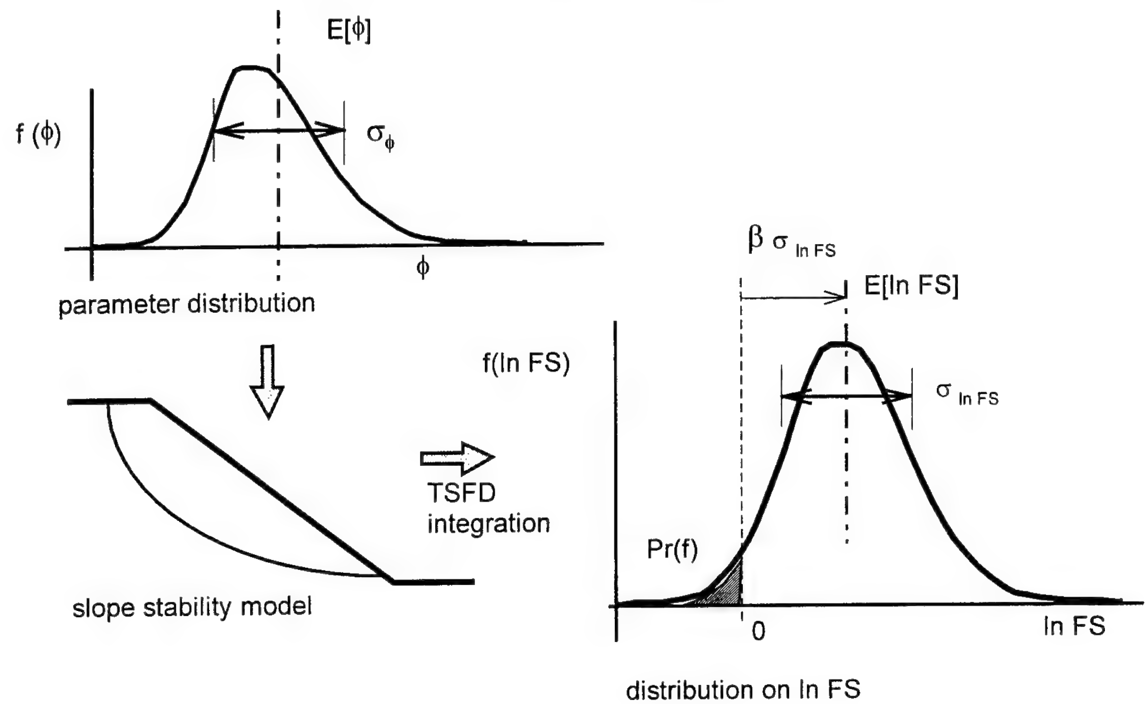

Figure 4. Probability of Failure, Reliability Index, and Method of Moments

For step 3, where sufficient data are available, the probabilistic moments may be calculated by standard statistical means. However, for many existing structures, they must be assigned from limited data and judgment based on similar structures. The standard deviation can be obtained by multiplying the expected value by an estimated coefficient of variation, based on a limited but growing body of data. Where no data are available, values can often be estimated by taking the engineers' judgment regarding reasonable parameter limits as corresponding to the expected value plus and minus 2.5 or 3.0 standard deviations.

For step 4, the moments of the performance function are estimated from the moments of the random variables. E[FS] can be approximated using the Taylor's series first-order, second-moment (FOSM) mean value approach as:

$$E[FS] = FS(E[X_1], E[X_2] \ldots E[X_n]) \tag{3}$$

where X_i represents the random variables such as c, ϕ, k_f, k_b, or z. In other words, the expected value of the performance function is taken as the value of the function evaluated at the expected values of the random variables.

Continuing with the Taylor's series approach, the standard deviation of the factor of safety is the square root of the variance of the factor of safety, which is calculated as

$$\mathrm{Var}[FS] = \sum \left(\frac{\partial FS}{\partial X_i} \right)^2 \sigma_{X_i}^2 + 2 \sum \left(\frac{\partial FS}{X_i} \frac{\partial FS}{X_j} \right) \rho_{X_i, X_j} \sigma_{X_i} \sigma_{X_j} \tag{4}$$

Where random variables are taken to be independent, the second summation drops out.

The partial derivatives are calculated at the expected value of each random variable. More sophisticated methods have been proposed, such as Hasofer and Lind's (1977) method, wherein the Taylor's series is expanded about an unknown "failure point" by successive iteration. This has the advantage of providing invariant solutions; however, its computational complexity presently limits its practicality for planning-level studies; each evaluation of a performance function requires a computer run, and the method requires considerable iteration. Using existing programs, the partial derivatives in Equation 4 may be estimated numerically, using finite differences, as

$$\frac{\partial FS}{\partial X_i} \approx \frac{FS(X_{i+}) - FS(X_{i-})}{X_{i+} - X_{i-}} \tag{5}$$

where X_{i+} and X_{i-} represent the random variable X_i taken at some increment above and below the expected value. Although a very small increment would give the most accurate value, Corps' practice has been to take the increment at $\pm$ 1 σ from the expected value. This large increment picks up some of the behavior of nonlinear functions over their most probable range, and leads to computational simplicity. With this increment and independent random variables, Equation 4 becomes:

$$\mathrm{Var}[FS] \approx \sum_{i=1}^{n} \left(\frac{FS(X_{i+}) - FS(X_{i-})}{2} \right)^2 \tag{6}$$

Finally, in step 5, β is calculated as previously shown in Figure 4:

$$\beta = \frac{E[\ln FS]}{\sigma_{\ln FS}} \tag{7}$$

The required probabilistic moments for ln FS are determined from the moments for FS as:

$$\sigma_{\ln FS} = \sqrt{\ln\left(1 + V_{FS}^2\right)} \tag{8}$$

$$E[\ln FS] = \ln\left(E[FS]\right) - \frac{\sigma_{\ln FS}^2}{2} \tag{9}$$

Although not absolute measures of reliability, β values provide consistent comparisons across performance modes and across structures. They permit comparing the relative reliability of one structure to another, the relative reliability of a structure for different performance modes such as slope failure and seepage failure, and the relative change in reliability of a structure subjected to changing loads, such as a levee embankment subjected to rising water levels.

Estimating Pr(f). With comparative reliability expressed as β, planners have a means compare the relative need for remedial work among several structures or components. Nevertheless, probability values Pr(f) are often desired as multipliers for the economic consequences of adverse performance. In this case, ln FS is *assumed* normally distributed and Pr(f) is taken as the cumulative probability for the standard normal distribution evaluated at -β standard deviations:

$$\Pr(U) = \Phi(-\beta) \tag{10}$$

While these are not precise probability values, due to the numerous assumptions, the resulting expected costs of alternatives are considered to provide valid comparisons.

EXAMPLE PROBLEMS

To investigate the relationships between Pr(f) and flood height, two example problems were analyzed in the research. Figure 5 shows one of these, a pervious sand levee overlying a thin clay top blanket which in turn overlies a thick pervious sand substratum. This section, although deliberately made steep and pervious to illustrate the change in Pr(f) with flood height, is not unlike some private levees along the upper Mississippi and Illinois Rivers. The second example was a clay levee on a clay top blanket with irregular geometry.

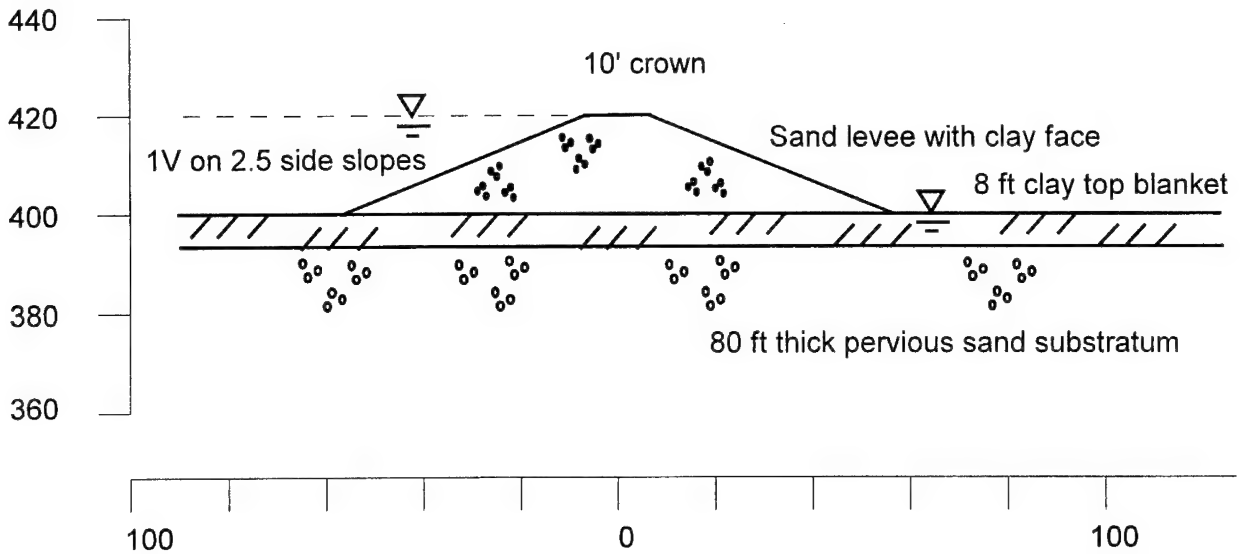

Figure 5. Cross-Section for Pervious Sand Levee Example

EXAMPLE UNDERSEEPAGE ANALYSIS

Using the methodology previously described, probabilistic underseepage analyses were performed for flood elevations ranging from el. 400, the natural ground surface, to el. 420, the levee crown. Random variables were characterized as shown in Table 1. Using the permeability values for the top blanket k_b and k_f, the moments of a new random variable, their ratio, was calculated using the TSFD method. E[FS] and var[FS] are calculated using Equation 6 as shown in Table 2 for the highest water elevation. These were used to calculate β, and converted to Pr(f) using Equation 10. The resulting function relating the conditional probability of underseepage failure to flood height is shown in Figure 6. The function is S-shaped, and Pr(f) is low for floodwater heights less than about one-half the levee height, even for an assumed cross-section intended to represent potentially deficient conditions.

Table 1
Random Variables for Underseepage Analysis, Sand Levee Example

Parameter	Expected Value	Standard Deviation	Coefficient of Variation
kf	0.1 cm/s	0.03 cm/s	30%
kb	1 x 10-4 cm/s	0.3 x 10-4 cm/s	30%
z	8.0 ft	2.0 ft	25%
d	80 ft	5 ft	6.25%

Table 2
Probabilistic Underseepage Analysis for Water at Elevation 420. (H = 20. ft)

Run	k_f/k_b	z	d	h_o	i	Variance	Percent of total Variance
1	1000	8.0	80.0	9.357	**1.170**		
2	600	8.0	80.0	9.185	1.148		
3	1400	8.0	80.0	9.451	1.181	0.000276	0.30
4	1000	6.0	80.0	9.265	1.544		
5	1000	10.0	80.0	9.421	0.942	0.090606	99.69
6	1000	8.0	75.0	9.337	1.167		
7	1000	8.0	85.0	9.375	1.172	0.000006	0.01
				Total		0.090888	100.0

The shape can be understood by reviewing Figure 5. At low flood heights, the normal curve representing ln FS is well to the right of the limit state. As the flood height increases, E[ln FS] decreases and the curve moves to the left, but $V_{\ln FS}$ tends to stay constant, keeping the width of the curve constant. The area under the curve below the limit state (i.e., Pr(f)) increases at an increasing rate, beginning at about 10 ft of head in the example. Once E[ln FS] drops below 0.0, occurring at about 15 ft of head in the example, the peak of the normal curve has moved below the limit state. Increasing heads continue to increase Pr(f), now in excess of 50%, but at a decreasing rate. The shape of the curve is also consistent with observations during floods; even substandard levee sections often perform adequately for low head conditions, but performance can deteriorate rapidly as water levels increase.

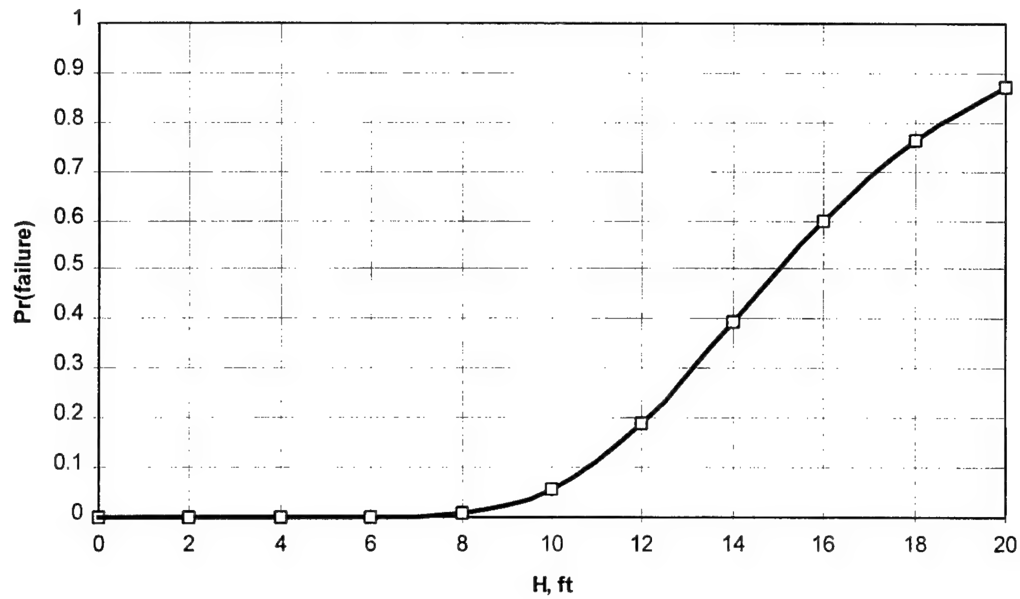

Figure 6. Probability of Underseepage Failure vs. Floodwater Elevation

EXAMPLE SLOPE STABILITY ANALYSIS

Slope stability analyses were performed for the sand levee example in Figure 5 for a range of water levels using UTEXAS2. Random variables were characterized as shown in Table 3. Two distinct piezometric surfaces were modeled in the two sand materials. The piezometric surface in the embankment was approximated as a straight line from the point where the flood water intersects the riverside slope to the landside levee toe. The piezometric surface in the foundation was obtained from the expected value condition in the underseepage analyses. This results in a piezometric surface in the foundation that is above the natural ground on the landside of the levee. Additional refinement could be made by making this piezometric surface a random variable.

Table 3
Random Variables for Slope Stability Analysis, Levee Reliability Example

Parameter	Expected Value	Standard Deviation	Coefficient of Variation
ϕ (embankment sand)	30 deg	2 deg	6.7%
s_u (clay foundation)	800 lb/ft^2	320 lb/ft^2	40%
ϕ (foundation sand)	34 deg	2 deg	5.9%

Changing strength parameters in the probabilistic analysis and changing piezometric surfaces as the water level increases both lead to changes in the location of the critical surface.

With flood water to elevation 410, critical surfaces occur both in the foundation clay and near the surface of the embankment (Figure 7). As the water level increases and piezometric levels rise in the sand embankment, the critical surfaces all move to the embankment.

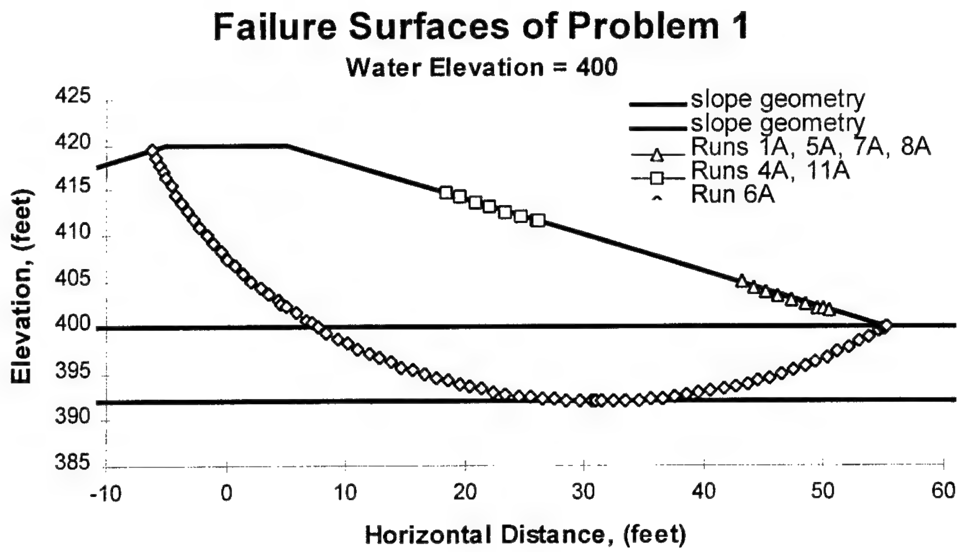

Figure 7. Critical Slip Surfaces for Floodwater to Mid-Height of Levee

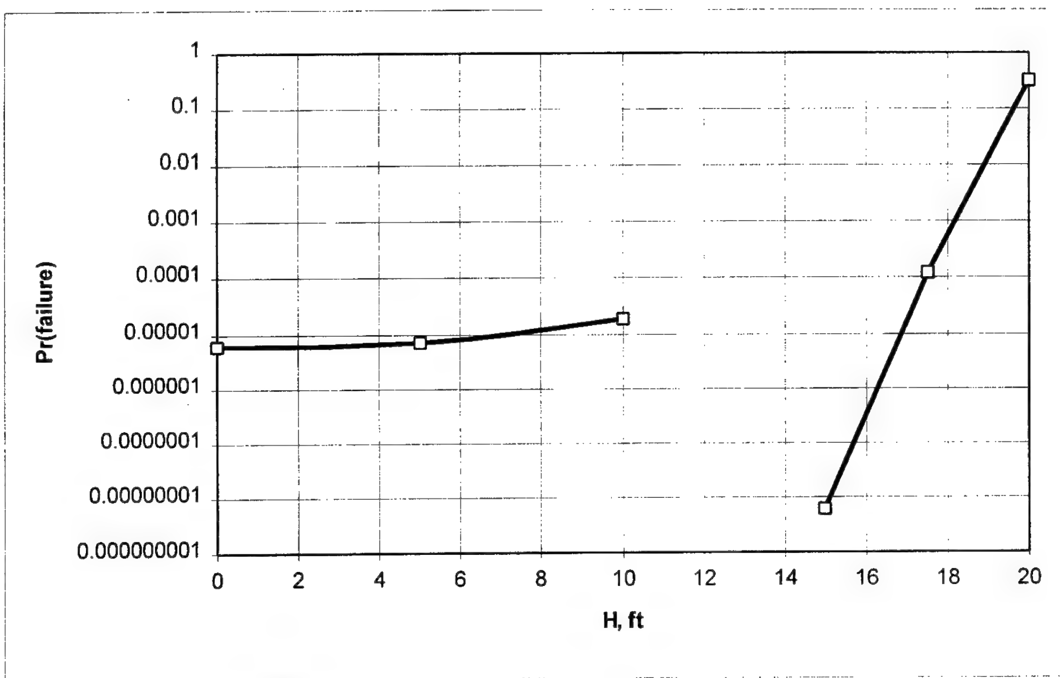

Figure 8. Probability of Slope Failure vs. Floodwater Height

The resulting conditional Pr(f) function for slope stability is shown in Figure 8. It is observed that Pr(f) is almost negligible until the flood water reaches about three-quarters the levee height, a point where the piezometric surface in the embankment begins to significantly affect the stability of potential shallow failure surfaces on the landside slope.

A discontinuity in Pr(f) is observed as the flood height is increased from 10 ft to 15 ft, Pr(f) abruptly decreases, then begins to rise again. This illustrates an interesting facet of probability analysis; Pr(f) is a function not only of the expected values of the factor of safety and the underlying parameters, but also of their coefficients of variation. In the present case, at a flood height between 10 and 15 ft, some of the critical surfaces move from the foundation clay, with a high coefficient of variation for its strength, to the embankment sands, for which the coefficient of variation is smaller. This decreases β and Pr(f). Even though the safety factor may decrease as the flood height increases, if the value of the smaller safety factor is more certain due to the lesser strength uncertainty, Pr(f) may decrease.

OTHER PERFORMANCE MODES

The curves in Figures 6 and 8 illustrate the conditional Pr(f) for only two failure modes. Other modes of potentially adverse performance include internal erosion from through-seepage, and external erosion due to seepage exit, current velocity, and wave attack. Preliminary approaches to analysis of some of these conditions are suggested in the research report (Wolff, 1994) and numbers are calculated for illustration; however, performance functions and limit states for these modes are not nearly so well developed and accepted as those for slope stability and underseepage.

BUILDING THE COMPOSITE FUNCTION

Where Pr(f) versus flood height functions can be developed for each possible performance mode, and where modes can be assumed independent, a total Pr(f) function can be developed by combining the probabilities as a series system. For an independent series system, the overall reliability R is given by

$$R = R_1 \, R_2 \, ... \, R_n \tag{11}$$

Applying Equation 11 at a series of flood water elevations gives:

$$R(FWE) = R_1(FWE) \, R_2\,(FWE) \, ... \, R_n\,(FWE) \tag{12}$$

Where modes have some correlation, as is likely the case for seepage and slope stability, the assumption of independence is conservative and leads to an upper bound on the probability.

Figure 9 shows the combined conditional probability-of-failure function for the sand levee example. The functions for underseepage and slope stability have previously been discussed. The function for through-seepage was developed using a modification of Rock Island

District design criteria for sand levees. The function for surface erosion was developed by assuming a critical scour velocity and comparing it to the river velocity using a simple Manning equation approach; more sophisticated models can undoubtedly be constructed using the Corps' HEC models. Finally, the "judgment" curve represents the probability values that can be assigned by the engineer for items not explicity modeled, such as observed cracks and animal burrows. Techniques to assign and calibrate such values require further study.

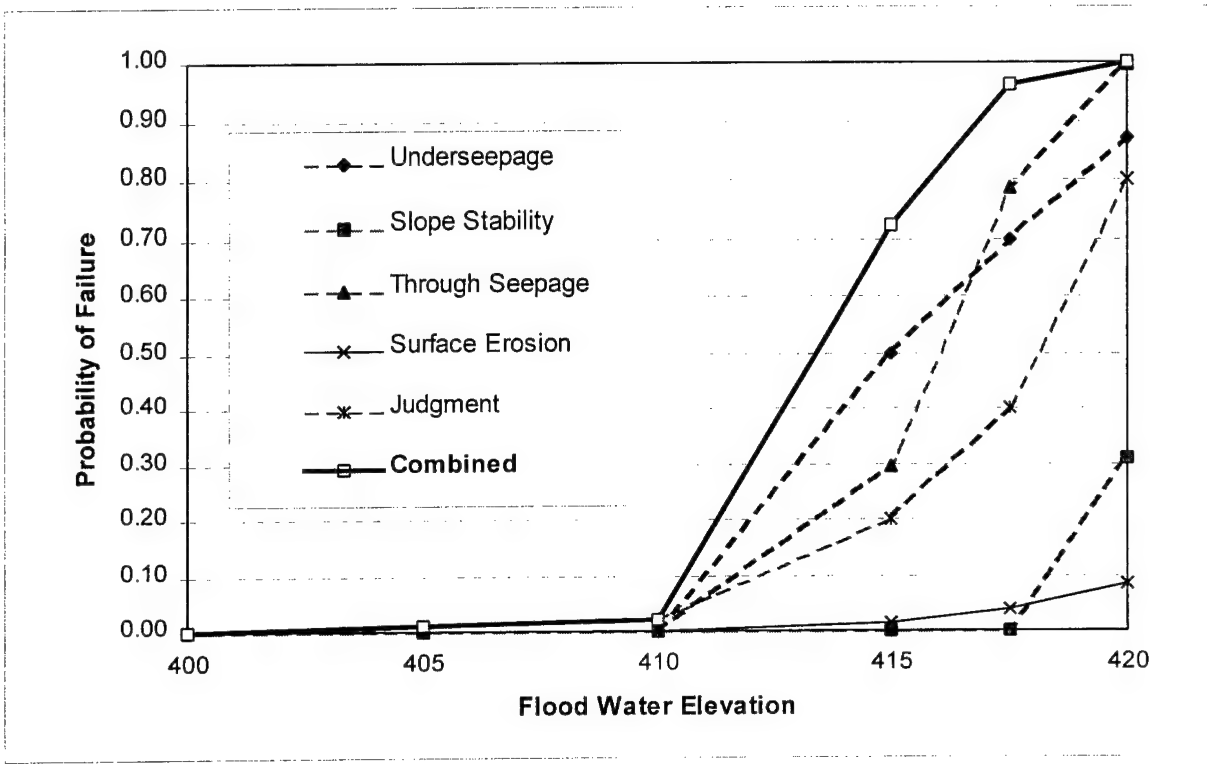

Figure 9. Combined Conditional Probability of Failure Function

REMAINING LIMITATIONS / AREAS FOR FURTHER STUDY

The illustrated methodology provides an important step to developing reliability functions that include site-specific information regarding soil conditions along a levee; nevertheless, there are many remaining limitations, and areas for further research. These are summarized in Appendix A to the forthcoming EC (Wolff and Shannon and Wilson, 1997). They include:

1. Varying interpretations regarding the interpretation of probabilistic slope stability analysis. A slope is a system of an infinite number of possible failure surfaces. As the critical surface in deterministic analysis does not in general, coincide with

that for probabilistic analysis, a number of approaches can be developed which yield different solutions.

2. Application of spatial correlation theory to soil parameters. As soil is a continuous medium, the appropriate characterization of uncertainty in a two-dimensional slope stability or seepage analysis is dependent on the size of the modeled area and free body.
3. Application of spatial correlation theory to long earth structures. Similarly, real levees may be many miles in length. Intuitively, a long levee is less reliable than a replicate shorter one. Elegant mathematical solutions are available to treat this problem, however, appropriate values to use in such models remain problematical

SUMMARY AND CONCLUSIONS

Planning studies for rehabilitation of Corps' projects now require quantifying the reliability of embankments and other engineering features. Performing reliability analyses of existing structures given resource constraints requires adapting probabilistic methods to use existing computer programs and developing some simple approaches that can be used where little or no test data are available. The reliability index concept, wherein uncertainty in performance is related to the uncertainty in underlying random variables, is gaining application for Corps' studies, and is a convenient approach for assessing levee reliability.

Given that Pr(f) can be calculated for different performance modes and different flood water elevations, these values can be combined to provide the desired conditional probability-of-failure functions; however, the underlying deterministic models for performance modes other than slope stability and underseepage warrant further study.

For levees subjected to increasing floodwater heights, the probability of failure versus floodwater height function is typically S-shaped. Probabilities of failure may be low at low heads, but reliability may deteriorate rapidly as flood water levels increase. This finding, supported mathematically herein, agrees with engineering intuition and observed behavior of levees during floods.

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RISK BASED ANALYSIS OF FLOOD DAMAGE REDUCTION ALTERNATIVES FOR THE UPPER DES PLAINES RIVER IN NORTHEASTERN ILLINOIS

by

Carolann Biegen [1]

ABSTRACT

Risk based analysis is evolving within the Corps and is being phased into all Corps planning and design studies. A risk based analysis has been applied to a flood damage reduction, draft feasibility study for the Upper Des Plaines River, a large watershed in northeastern Illinois. The HEC-FDA risk and reliability format was used to evaluate the feasibility of several flood damage reduction measures by evaluating the engineering and economic performance of each alternative. Results from the analysis have provided a comprehensive comparison of the flood damage reduction alternatives and the expected benefits accrued by location and damage category. In addition, the reliability of the flood damage reduction alternatives has been ascertained at various locations along the river.

STUDY SETTING

The Des Plaines River originates in Racine and Kenosha Counties in southeastern Wisconsin where the basin is primarily agricultural. The river enters Illinois in Lake County, flowing southward through urbanized Cook County to Riverside, Illinois (Figure 1). Beyond Riverside, the river curves to the southwest eventually merging with the Chicago Sanitary and Ship Canal, the DuPage River and the Kankakee River near Joliet, Illinois and forms the Illinois River. Except for the upper reaches in Wisconsin and northernmost Illinois, most of the study area is densely populated with considerable development in areas adjacent to the river's floodplain. Despite the highly urbanized character of much of the project area, the river has many natural, scenic, and recreational characteristics including riparian woods along 34 percent of its length.

The Des Plaines River is a primary drainage feature in northeastern Illinois. The river valley can be as wide as one mile, with the river channel itself on the order of 200 to 250 feet wide. From Wisconsin to the junction of the Des Plaines River and the Chicago Sanitary and Ship Canal the average river slope is approximately 1.3 feet per mile. The watershed is aligned primarily along a north south axis with a length of 82 miles and an average width of 9 miles. The drainage area of the watershed at Riverside, including the Salt Creek tributary, is 630 square miles. The length of the river is approximately 70 miles from the headwaters in Wisconsin to the study limits in Riverside, Illinois. Within this limit there are 4 mainstem United States Geological Survey (USGS) gaging stations with records ranging from 37 years at Russell to 83 years at Riverside - see Figure 1.

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The Upper Des Plaines River is subject to severe overbank flooding due to inadequate channel capacity to carry peak flows during major storm events. Flooding impacts homes, commercial and industrial sites, public and municipal sites, transportation network, cemeteries, golf courses and other recreation and open space areas. Average annual flood damages are estimated at $21,407,000. The feasibility study is aimed at evaluating and recommending flood damage reduction alternatives including 11 detention facilities totaling 9,540 acre-feet, 5 levees totaling over 6 miles in length, and other non-structural alternatives (Figure 1).

RISK AND RELIABILITY AS RELATED TO A FLOOD STUDY

Imperfect knowledge of the "true" nature of the hydrology and hydraulics in an area creates uncertainty in the design of flood control projects and in the determination of their reliability. Risk-based analysis provides a method to explicitly quantify the uncertainties associated with the primary relationships required in flood damage reduction projects:

1) Hydrology: flood discharge versus flood frequency,
2) Hydraulics: flood stage versus flood discharge, and
3) Economics: flood damage versus flood stage.

Risk based analysis methods provide statistical information on the reliability of predicted flood levels and the probability of those levels being exceeded. In addition, a risk based analysis provides a measure of the engineering and economic performance of proposed projects. The risk and reliability analysis for the Upper Des Plaines River study was performed following current Corps guidelines and using the current Corps of Engineer's Hydrologic Engineering Center's (HEC) flood damage analysis program, HEC-FDA (USACE, 1996a). Both HEC and the Corp's Institute for Water Resources (IWR) were contracted by the Chicago District for assistance in developing the basin-wide risk and reliability analysis for the Upper Des Plaines River. The analysis followed the general guidelines presented in the current EM 1110-2-1619 (USACE, 1996b) and the strategy developed by the Chicago District and representatives from HEC and IWR. The primary data required to carry out the risk-based reliability analysis are:

1) A best estimate of discharge-frequency curves along the river,
2) A best estimate of stage-discharge rating curves along the river,
3) A best estimate of stage-damage relationships along the river and,
4) A statistical description of the uncertainty inherent in these three relationships.

DAMAGE REACH BREAKDOWN

In accordance with the HEC-FDA format, the Upper Des Plaines River 70 mile study limit was subdivided into 27 damage reaches. Each damage reach was defined by an upstream and downstream river mile as well as an index node. Individual damage reaches along the 70 mile long study limit ranged from 0.2 to 10.4 miles in length. All hydrologic and hydraulic characteristics of the damage reach are defined at a chosen index node within the damage reach. Economic characteristics, such as stage-damage relationships, are aggregated over the entire reach length and total reach damages are then defined at the representative index node.

The 27 damage reaches were chosen with regard to locations of existing gaging stations, locations of large flow changes due to tributaries, state, county and municipal boundaries, locations of proposed detention facilities and at existing and proposed levee locations. At each proposed levee site two damage reaches were necessary; one to define characteristics of the protected (with levee) river bank and one to define characteristics of the unprotected river bank. In the case of a ring levee, all structures that physically shared the same bank, yet were not protected by the ring levee, were relocated to the unprotected bank in the HEC-FDA model.

DISCHARGE-FREQUENCY AND UNCERTAINTY

A flood discharge-frequency analysis provides an estimate of probability for different magnitudes of flood events. Discharge-frequency curves were taken from the HEC-1 (USACE, 1990a) baseline hydrologic model which was calibrated to the adjusted discharge-frequency curves at the four mainstem gages (based on an annual series and the expected, not computed, probability). The discharge-frequency relationships along the mainstem river were then imported to the HEC-2 (USACE, 1990b) hydraulic model for the development of synthetic water surface profiles. Through statistical methods the uncertainty in the discharge-frequency estimates was quantified with a consideration of the quality of data used to produce the adopted curves. Primarily, this is dependent on the availability of gages on the river, the number of years of record at those gages and the quality of the model calibration to these gages.

Results from the baseline condition (without project) HEC-2 hydraulic analysis were imported into HEC-FDA to define the discharge-frequency relationship at each of the river miles corresponding to the 27 index nodes. Development of the uncertainty about the discharge-frequency relationships required the use of a graphical probability distribution to achieve a good fit. The graphical probability distribution is based on the method of order statistics as described in EM 1110-2-1619. The uncertainty is developed by assuming a normal distribution about the discharge-frequency curve and adopting an equivalent number of years of record to develop the distribution. Using these values the HEC-FDA model calculates the discharges at other frequencies and develops confidence bands for the range of frequency events. For each of the 27 damage reaches, the equivalent number of years of record was determined with a consideration of the four mainstem Des Plaines River USGS gaging stations. For each of the four damage reaches that contained a mainstem gage, the equivalent number of years of record was chosen as the historic record length for the appropriate gage. A straight line interpolation was used to determine the equivalent number of years of record for the damage reaches between gages.

The method of order statistics was also used for the project condition, with detention components in place, as would be expected due to the regulating effects that reservoirs have on discharge-frequency curves. A standard deviation of errors about the regulated discharge-frequency curve was developed using the method of ordered statistics and an equivalent record length. The equivalent record length under project conditions was specified as 90% of the record length determined at each damage reach under baseline conditions. For this phase of study, it was assumed that the presence of levees did not impact the discharge-frequency curve. That is, for analyzing project conditions with levees only, the baseline condition discharge-frequency and associated uncertainties were used. The discharge-frequency relationships and deviation values

for the baseline condition with storage components were also used for the baseline condition with storage components and levees.

STAGE-DISCHARGE AND UNCERTAINTY

The stage-discharge relationships along the river were developed using the HEC-2 computer backwater model under baseline and project conditions. EM 1110-2-1619 recommends a series of methods to determine a standard deviation value to develop a normal distribution about the stage-discharge curve. These methods include; using measured streamflow versus measured stage data and observing scatter within measurement periods as well as changes in the adopted rating curves over time, comparing high water data to hydraulic modeling results, and running a Manning's roughness coefficient ("n" value) sensitivity analysis to determine effects on predicted stages. Finally, the guidance gives minimum standard deviation values to adopt based on the accuracy of the survey(s) used to determine cross-sections for the hydraulic model. The above methods were utilized in determining standard deviations for the stage-discharge curves for each of the 27 damage reach index nodes.

Variations in USGS gage flow measurements over several decades were plotted at each of the 4 mainstem gages. These stage-discharge plots show the variation in the measured stage-discharge relationships over time and over a range of discharges. The maximum stage difference between the upper and lower limits of the curve was read at the 1% chance event discharge where available. If the curve did not extend to the 1% event discharge, the maximum stage difference between the projected upper and lower limits was read at the highest discharge. This determination was repeated at the four gages and maximum stage differences were: 2.8 feet at Russell, 2.6 feet at Gurnee, 3.0 feet at Des Plaines and 0.8 feet at Riverside.

A comparison of how the USGS adopted stage-discharge curves change over time was also considered. The maximum difference between the upper and lower limits was read at the highest discharge values if the curve did not extend to the 1% chance event. Maximum stage differences at the four gages were: 0.5 feet at Russell, 2.4 feet at Gurnee, 2 feet at Des Plaines and 0.4 feet at Riverside.

The 1986 flood event was used as a comparison of measured high water data to an HEC-2 computed water surface profile throughout the study limits. The HEC-2 water surface profile was generated and a plot was made with the high water marks placed at the locations where data was available. The simulated water surface profile along with the high water data was used to develop upper and lower limits of the water surfaces. Maximum stage differences between the upper and lower limits were determined for each of the 27 damage reaches. At the four mainstem gages these values ranged from 0.5 feet at the Gurnee gage to 1.3 feet at the Russell Road gage. Values were greater than and less than those reported at the gages for damage reaches located between gages.

The final method used to determine a maximum stage difference was a Manning's "n" sensitivity analysis performed for the 1% chance flood event using HEC-2. Maximum and minimum "n" values adopted were the calibrated "n" value multiplied by 1.25 and 0.75,

respectively, for the lower portion of the river and 1.35 and 0.65 for the upper reaches of the river. The Manning's "n" sensitivity was split into two reaches due to the variability of stream and streambank conditions throughout the Des Plaines River. Typically the upper portion of the watershed from the Russell Road gage down past the Gurnee gage experiences log jams and overhanging vegetation. In this reach a higher "n" multiplier was used. At the gages, maximum stage differences between the upper and lower "n" water surface profiles ranged from 1.7 feet at the Riverside gage on up to 4.0 feet at the Gurnee gage.

Based on EM guidelines, the final standard deviation to apply to the stage-discharge relationship can be approximated by taking the maximum differences between the upper and lower limits, as determined by the 4 methods above, and dividing by a factor of 4. The divisor of 4 is based on the assumption that the maximum difference encompasses 95% of the possible values, thus equating to a total of 4 standard deviations or 2 standard deviations (+/-) on either side of the mean. Standard deviation values were developed for the 27 damage reaches along the entire Upper Des Plaines River study limit based on the results of the above described methodology. Of the 27 standard deviation values developed only three were adopted; 0.4 feet for the lower reaches of the river from river mile 44.5 to 49.6, 0.5 feet for the middle reach from river mile 49.6 to 89.3 and 0.6 feet in the upper reaches of the river from river mile 89.3 to 110.3. These values compared well to the minimum requirements stated in Table 5-2 of the EM based on the source of the study's cross-section data and a fair to good calibration associated with the hydraulic analysis.

The 1% event standard deviation values as determined above were linked to the HEC-2 derived stage-discharge relationships in the HEC-FDA program. At each of the 27 damage reaches, HEC-FDA computes the standard deviation values for events less than and greater than the 1% event. For purposes of this analysis, the 1% chance event was determined to be the event at which to apply the stage-discharge standard deviation. HEC-FDA takes the 1% event, stage deviation value and proportions the deviation value down the stage-discharge curve to 0 feet at 0 discharge. That is, discharges between 0 cfs and the 1% event have increasing stage deviation values from 0 feet on up to the given 1% event deviation value. The 1% event, stage deviation value is adopted for those events exceeding the 1% event.

STAGE-DAMAGE AND UNCERTAINTY

A significant economic database including a floodplain structure and traffic inventory had previously been created for earlier stages of the Upper Des Plaines River Feasibility Study. As part of this study six damage categories were identified, three of structural nature and three related to traffic:

1) Structural: Residential
2) Structural: Apartment
3) Structural: Commercial, Industrial, Public (CIP)
4) Traffic: Delays due to Floods
5) Traffic: Post-Flood Repairs
6) Traffic: Delays due to Repairs

An external program was developed to import the multiple economic databases associated with the three structural inventories into the HEC-FDA program. These databases included; structure value, content value, first floor elevation, river mile and river bank designation. HEC assisted the District in importing the structural databases and IWR assisted in the import of the traffic databases into the HEC-FDA format. The stage-damage relationships, as typically compiled for any flood study, were augmented with information to ascertain the uncertainty about the relationships. The six economic parameters were individually analyzed with regard to uncertainty in their stage-damage function and composite stage-damage relationships were developed for each of the 27 damage reaches.

Structure Damage Evaluation

The Des Plaines River flooding of 1986 and 1987 and the synthetic water surface profiles served as a good indicator of the areas vulnerable to flood damage. Several highly damaged areas were inventoried by the State of Illinois after the 1986 and 1987 flood events. The State conducted structure inventories that were adopted in the current evaluations. In other specially designated areas, field surveys were contracted for determination of first floor elevations and structure type information - specifically for those structures within the 0.2% chance exceedance floodplain. The contract surveys covered an additional 568 structures: 418 single family residences, 150 commercial-industrial-public structures as well as apartment and townhouse units.

These field surveyed investigations were supplemented with a combination photo and field survey that utilized 1 foot contour-ortho maps to estimate first floor elevations. In addition, windshield surveys were used to establish the type of structure and to capture observable CIP structure features via a photograph. This information was used in the selection of the appropriate depth-damage functions to be used in the economic analyses.

Upon completion of the above surveys, three basic structure inventories were compiled: a single family housing inventory totaling 4,204 structures in 76 clusters; an apartment and townhouse unit inventory totaling 2,286 units in 126 clusters; and a CIP structure inventory totaling 687 structures in 687 clusters. If a number of structures and units were affected by overbank flooding from a common location, then they were clustered and analyzed as a group at that location. Due to their less common features, CIP structures were kept to individual clusters.

The inventories contain the vital parameter values necessary to evaluate flood damage potential. These parameters are: the structure location referenced to an overbank (left or right) and a river mile designation, the structure type code used to assign an appropriate depth-damage function for structure and content, the first floor elevation of the structure to which the depth-percent damage functions are referenced, the structure value estimate, and the content value estimate within the structure.

The depth-percent damage functions for residential and apartment structures were based on the Federal Flood Insurance Administration curves. Actual damage claims from the 1986 and

1987 flood events along the Des Plaines River were extracted from a FEMA database and were used to adapt these curves to the Des Plaines River area. For CIP structures, a catalogue of depth-percent damage functions developed and used at the Baltimore/Galveston Corps District offices was referenced (IWR, 1985), modified, and ultimately applied to the CIP structures within the current study. Flood damage computer programs developed by the Chicago District and used in previous District flood damage evaluations were used to perform the multiple depth-damage computations.

Uncertainty in the Residential - Structure Category

Uncertainty characterizations for the residential damage estimates included: 1) first floor elevations, 2) structure value, 3) content to structure value, and 4) the depth - percent damage functions for both structure and contents as computed per structure type. The uncertainty in the first floor elevation is dependent on the source of the inventory (field survey or topographic map) from which elevations were assigned. A normal distribution with a 0.3 foot standard deviation was used for the uncertainty in the elevation component. Uncertainties in the structural value were computed assuming a normal distribution with a +/- 10% deviation. Specific content values were determined by multiplying the structure value by a ratio of 0.52. This ratio was assumed to have an uncertainty about it, defined by a normal distribution and standard deviation of 0.51. Uncertainties associated with the depth - percent damage functions were assigned a normal distribution and were determined from an analysis of original FEMA damage claims, both at a national level and specific post flood claims from the study area.

Uncertainty in the Apartment and CIP - Structure Categories

The uncertainty characterization of the apartment and CIP structures categories included several considerations. Uncertainty in the first floor elevation was assigned a normal distribution and a 0.3 foot standard deviation. Uncertainties in the structural value were computed assuming a normal distribution with a +/- 8% and +/- 25% deviation for the apartment and CIP categories, respectively. Statistical analyses were undertaken to determine uncertainties about the content values for the apartment and CIP categories. Uncertainties were distributed normally with deviations of +/- 8% and +/- 25% for the apartment and CIP structure categories, respectively.

Traffic Damage Evaluation

During the 1986 and 1987 flood events, many communities experienced flooding on major roads that impeded, and in some cases prevented, normal and emergency travel thereby resulting in significant damages. To quantify the damages associated with roadway flooding, the transportation analysis identified 50 major roads likely to flood, mapped the detour routes around the flooding, determined the costs associated with using the detour routes and determined the costs associated with residual flooding such as road repair and replacement. The transportation damages were classified in three categories:

1) Flood detour costs (i.e., costs resulting from taking detour routes during flooding),
2) Road repair costs (i.e., costs of damage to the physical structure of the roadway),
3) Construction repair detour costs (i.e., costs arising from the use of detour routes during post-flood reconstruction and repair).

The traffic delay, detour analysis calculated the cost of the extra time and additional mileage incurred by using detour routes over the period of time a road is flooded. The amount of time a roadway is flooded (flood duration) is a primary determinant of traffic damages. With increasing severity of flood events (i.e., from the 2% chance exceedance event to the 1% event), both the flood duration and number of flooded streets increase, leading to more traffic detours with a longer duration. Delay costs were based on the number of vehicles detoured, the additional time and distance involved, and the duration of time flood detours are in effect.

Road repair costs were based on the U.S. Department of Transportation, Federal Highway Administration (USDOT, 1981) report of roadway and embankment flood impacts. This report relates depth and duration of flood events with percentages of roadway loss. Repair costs were computed based on the amount of embankment and pavement needed for repair. Costs associated with delays due to repair were computed by using the flood traffic delay model with durations and detours resulting from construction operations rather than road flooding and closures.

Uncertainty in the Flood Detour - Traffic Category

Uncertainties in flood detour damages arise from a number of contributing quantities, each of which has some associated degree of uncertainty. Four categories of uncertainty were identified as the main ones to consider in assessing a general uncertainty about the flood detour, damage category. The four categories and their assumed uncertainty distributions are:

1) Vehicle cost per mile - triangular distribution,
2) Daily number of vehicles - triangular distribution,
3) Duration of road closure - triangular distribution, and
4) Elevation of the roadway - normal distribution.

The categories for vehicular cost per mile and daily number of vehicles were assumed to have a range of +/- 10 percent under a triangular distribution. Uncertainty about the actual duration of road closure was assumed to have a triangular distribution with an expected range of +/- 12 hours with the durations restricted to non-negative values. Variability in the roadway elevation, as with first floor elevations, was assumed to have a normal distribution with a mean of zero and a standard deviation of 0.3 feet, based on the topographic maps and the Corp's EM 1110-2-1619 criteria.

Uncertainty in the Road Repair - Traffic Category

Several quantities were assumed to be variable in the determination of road repair costs, such as:

1) Volume of embankment - triangular distribution,
2) Area of pavement - triangular distribution,
3) Unit cost of embankment repair - triangular distribution, and
4) Unit cost of pavement repair - triangular distribution.

All four categories above were assumed to have a range of +/- 10 percent using the assumed triangular distribution.

Uncertainty in the Repair Detour - Traffic Category

Uncertainties in detours during repair operations were developed in a similar fashion to those developed for detours due to flooding. Where flood depths and durations defined the extent and duration of detours due to flooding, the number of days until repairs are completed defines the duration of detours due to repair operations. A triangular distribution was used with the maximum repair time being defined as that estimated with one, ten hour work shift per day. The most likely repair time was assumed as one using a 24 hour work shift per day. The minimum repair time was assumed to be 10 percent less than that determined for the most likely time.

ANALYSIS OF RISK AND RELIABILITY

The hydrologic and hydraulic relationships were combined with the stage-damage relationships to develop a risk and reliability analysis using the HEC-FDA program. The HEC-FDA program incorporates a Monte-Carlo simulation to sample the interaction among the various hydrologic, hydraulic and economic relationships and their individual uncertainties. The Monte-Carlo simulation routine randomly samples a discharge over a range of frequencies and within the confidence bands of the discharge-frequency curve. At that discharge, the routine then samples between the upper and lower confidence band of the stage discharge curve and randomly chooses a stage. At that stage, the routine samples between the upper and lower confidence bands of the stage-damage relationship and chooses a corresponding damage. This is an iterative process which is repeated until a statistically representative sample is developed.

Reliability statistics are based on the results of the Monte-Carlo random sampling. The number of Monte-Carlo simulations is chosen internally to the HEC-FDA program and represents the number of random samples for each reliability analysis. As described above, the incorporation of uncertainty about both the stage-discharge, discharge-frequency, and stage-damage relationships is inherent in the random sampling. For each damage reach and each plan the Monte-Carlo simulation proceeds until a minimum criteria, representing the acceptable change in sample mean and standard deviation, is reached. Once the criteria is satisfied at one reach the model proceeds with a Monte-Carlo simulation on the next reach and continues for all 27 damage reaches. The resulting damage-frequency relationships and expected average annual damages are reported for each of the 27 damage reaches and for the study area as a whole.

The HEC-FDA program was used to study the Upper Des Plaines River under four different scenarios:

1) Baseline Condition - no projects in place,
2) With Detention - with 11 flood control detention components only,
3) With Levees - with 5 levee components only, and
4) With Detention and Levees - with 11 detention and 5 levee components.

The baseline condition HEC-FDA model was developed using the previously described hydrologic, hydraulic and economic factors and their associated uncertainties. The three flood damage reduction measures and the baseline condition inputs to HEC-FDA are presented below.

BASELINE - NO PROJECT

Baseline condition, water surface profiles were imported from the corresponding HEC-2 output for determination of the graphical discharge-frequency relationships and the stage-discharge relationships at the 27 index nodes. Uncertainty in these relationships was determined using the methods previously described. The baseline conditions stage-damage relationships, described above, were used in all four scenarios.

For this study, discharges and stages associated with eight synthetic events (99%, 50%, 20%, 10%, 4%, 2%, 1%, and 0.2% chance exceedance events) were used to define the baseline condition. The baseline condition damages excluded areas that are being protected by existing and currently planned flood protection.

WITH DETENTION ONLY

Eleven detention components, totaling 9,540 acre-feet, are proposed as part of the Upper Des Plaines River flood damage reduction plan. The detention only condition was tested in HEC-FDA and used the imported HEC-2 water surface profiles computed with the detention facilities. Discharge-frequency and stage-discharge relationships for the with detention plan were developed using this HEC-2 water surface profile. Relationships were read in for each of the index nodes representing the 27 damage reaches. The baseline conditions stage-damage relationships, as previously described, were used in all four scenarios.

WITH LEVEES ONLY

Residual damages were evaluated and 5 levees were proposed to protect the localized areas that still experienced high residual damages even with the detention plan in place. The proposed levees were analyzed individually in HEC-FDA. Optimal levee heights were determined by comparing the HEC-FDA derived benefits to estimated costs at the various levee heights tested. The 5 levee heights tested corresponded to protection from the 4, 2, 1, 0.4 and 0.2 percent chance exceedance events at the five levee locations. For the levees only analysis, it was assumed that discharge-frequency and stage-discharge relationships were equivalent to those defined in the baseline - no project condition described above.

Results from the levee analysis included expected annual damage reduced for each levee at each height tested. The tested levee heights were checked for feasibility by determining the costs for each height. A review of these items allowed for the determination of the final levee heights which maximized net benefits. The optimized levee heights at the 5 levee locations were then incorporated into HEC-FDA for the final analyses; levees only and detention plus levees.

WITH DETENTION AND LEVEES

The 5 optimized levees were added to the 11 detention components for the final plan analyzed. This final plan was developed by importing the HEC-2 water surface profiles as developed for the detention component plan and using that profile to determine discharge-frequency and stage-discharge relationships. The five optimized levees were accounted for within the HEC-FDA platform. The baseline conditions economic relationships, as previously described, were used except in the five reaches containing the proposed levees. In those reaches the stage-damage relationships were modified according to the degree of protection provided by the levee.

RESULTS AND DISCUSSION

Results from the HEC-FDA analysis showed that expected annual damages would be approximately \$21,407,00 for baseline conditions with no project in place. This result is 15 percent higher than the baseline value predicted by traditional economic methods (\$18,648,000). This difference is primarily due to the inherent statistical effect of uncertainty in the higher estimates as related to the discharge-frequency, stage-discharge and stage-damage relationships. EM 1110-2-1619 states that the error in damage at any stage is not symmetrically distributed around the mean damage. This is particularly true at the lower stages, because damage values cannot be negative. Thus the probability of overestimating damage is greater with a risk and reliability analysis than with traditional economic methods. The difference between the two methods of analysis is typical of risk based analyses and was not considered unreasonable. The \$21,407,000 expected annual damage value was accepted by the Chicago District for baseline conditions damages.

Results from the risk and reliability analysis of the detention only plan indicated an expected annual residual damage of \$16,774,000, a reduction of \$4,633,000 (22 percent) when compared to baseline conditions. The five levees at their optimized heights were incorporated into an HEC-FDA analysis of levee components only. The combination of the five optimized levees resulted in an expected annual residual damage of \$17,128,000 or a \$4,279,000 expected annual damage reduction when compared to baseline results. The final scenario tested was the optimized levees in combination with the detention components. The HEC-FDA analysis of the levee plus detention plan resulted in \$13,200,000 for expected annual residual damages. This equates to a \$8,207,000 reduction of damages over the baseline condition expected annual damage. A summary table of expected annual damages and the reliability of those estimates is shown in Table 1 for the four plans analyzed.

Table 1. HEC-FDA Computed Reliability of Expected Annual Damage Estimates

Alternative	HEC-FDA Computed Expected Annual Damage (x $1,000) Without Project	With Project	Damage Reduced	Probability that Damage Reduced Exceeds Stated Value 0.75	0.50	0.25
No Project	21,407	21,407	0	0	0	0
Detention Only	21,407	16,774	4,633	2,019	4,345	6,248
Levees Only	21,407	17,128	4,279	2,380	3,781	5,567
Detention + Levees	21,407	13,200	8,207	3,798	7,351	10,870

As an example, the above table shows that there is a 75 percent chance that the annual damage reduced by the detention and levee alternative would exceed $3,798,000 and there is a 25 percent chance that annual damages reduced would exceed $10,870,000. Therefore, it can be said that there is a 50 percent chance (75 - 25) that annual damages reduced would lie somewhere between $3,798,000 and $10,870,000. These results quantify the uncertainty of the project and the expected range of damage reduction (benefits). A breakdown of residual damages by damage category for each of the alternatives tested is shown in Table 2 below. Preliminary costs of the project alternatives are undergoing final reviews and are included for comparison purposes only.

Table 2. HEC-FDA Computed Residual Damages by Category for Four Alternatives

Alternative	Expected Annual Damage (x $1,000) by Category						Total Residual Damage	Avg.Ann. Project Cost (x $1,000)
	Structural Damages			Traffic Damages				
	Res.	Apt.	CIP	Flood Detour	Road Repair	Repair Detour		
Baseline	2,547	1,683	1,558	5,064	1,701	8,854	21,407	0
Detention Only	2,099	1,367	1,135	3,977	1,507	6,689	16,774	4,797
Levees Only	1,181	777	985	4,881	1,394	7,910	17,128	1,204
Detention + Levees	1,062	707	767	3,946	1,362	6,002	13,846	6,001

Finally, the HEC-FDA program allows the user to determine the reliability of the performance of the proposed projects. That is, given a target stage within a particular damage reach, HEC-FDA will determine the probability that that stage will not be exceeded under baseline conditions and as a result of any project tested.

Large watershed analyses that require a large number of damage reaches for adequate evaluation present a challenge regarding how best to summarize a project's performance over each of the damage reaches. Damage reduction and a design level of protection are generally the two key factors of interest in defining and describing project performance. For the HEC-FDA analysis, HEC recommends that a unique target elevation in each reach be established by 1) defining the event frequency target and 2) defining an acceptable level of residual damage as a percentage of the chosen event frequency. With this general criteria, a unique target level (elevation) is established, based on baseline conditions, for each damage reach within the system. For damage reaches containing proposed levees, the target stage defaults to the top of levee

elevation. For reaches containing existing levees, the target stage falls somewhere below the top elevation at a user specified probable failure point based on geotechnical and other considerations.

The goal of any flood control measure in any plan being evaluated, other than levees, is a reduction of damages through a reduction in stage. A measure of project performance, then, can easily be documented for multiple reaches over multiple events for any given plan using the standard risk based techniques. If reliability statistics are tabulated against consistent target stages for each plan analyzed then performance levels can be assessed and compared between plans in a systematic fashion. These results are detailed for each damage reach and each plan in the HEC-FDA output. An overview of general project performance across the watershed and between plans can be documented in a manageable and understandable format using these tools.

The target stages for the Upper Des Plaines River study were determined by defining the following variables in HEC-FDA: 1) the event exceedance probability set at the 1 percent chance exceedance event and 2) the percent residual damages set at 5 percent. These values are used to set a target stage at that elevation which corresponds to a damage equivalent to 5 percent of the 1 percent chance event's damages. Where, for each damage reach 5 percent of the baseline condition's 1 percent storm event's resultant damages is considered an "acceptable" level of residual damage. This is a concept consistently applied in determining the target stage for all damage reaches evaluated and allows for a reasonable comparison between alternatives tested. Results are shown in Table 3 for four damage reaches, three having the highest baseline damage.

SUMMARY

A risk and reliability analysis has been successfully applied to a flood damage reduction study for the Upper Des Plaines River in northeastern Illinois. The Corp's HEC-FDA model provided a systematic analysis of risk and reliability for the 27 damage reaches within the study limits of the Upper Des Plaines River and allowed the risk analysis to be completed in an expeditious and economical fashion. Results from the analysis have provided a comprehensive comparison of the flood damage reduction alternatives and the expected benefits accrued by location and damage category. In addition, the reliability of the flood damage reduction alternatives has been ascertained at 27 locations along the river.

Table 3. Project Performance at Four Damage Reaches

Damage Reach (river mile)	Target Stage (feet NGVD)	Expected Annual Probability of Exceeding Target Stage	- Long Term Risk - Probability of Exceedance in 'x' years 10	25	50	Conditional Non-Exceedance Probability by Event (%) 10%	2%	1%
Baseline								
49.6 - 60.0	622.0	0.06	0.45	0.78	0.95	0.89	0.08	0.02
71.7 - 76.5	639.4	0.05	0.42	0.74	0.93	0.89	0.18	0.08
80.0 - 89.3	645.8	0.06	0.47	0.79	0.96	0.85	0.12	0.04
93.4 - 95.9	664.5	0.11	0.69	0.94	1.00	0.47	0.02	0.01
Detention Only								
49.6 - 60.0	622.0	0.05	0.38	0.70	0.91	0.94	0.15	0.04
71.7 - 76.5	639.4	0.04	0.32	0.62	0.86	0.96	0.31	0.15
80.0 - 89.3	645.8	0.06	0.44	0.77	0.95	0.85	0.21	0.11
93.4 - 95.9	664.5	0.11	0.67	0.94	1.00	0.50	0.05	0.02
Levees Only								
49.6 - 60.0	622.0	0.06	0.45	0.78	0.95	0.89	0.08	0.02
71.7 - 76.5	639.4	0.05	0.42	0.74	0.93	0.89	0.18	0.08
80.0 - 89.3	645.8	0.06	0.47	0.79	0.96	0.85	0.12	0.04
93.4 - 95.9 Gurnee Levee	667.3 Top of Levee	0.02	0.18	0.39	0.62	1.00	0.62	0.38
Detention + Levees								
49.6 - 60.0	622.0	0.05	0.38	0.70	0.91	0.94	0.15	0.04
71.7 - 76.5	639.4	0.04	0.32	0.62	0.86	0.96	0.31	0.15
80.0 - 89.3	645.8	0.06	0.44	0.77	0.95	0.85	0.21	0.11
93.4 - 95.9 Gurnee Levee	667.3 Top of Levee	0.02	0.15	0.34	0.56	1.00	0.72	0.52

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RISK BASED ANALYSIS OF BEARGRASS CREEK, KY

By

Neil O'Leary

Background.

This paper summarizes the Louisville District's experiences in conducting a risk based analysis of flood damage reduction alternatives for the Beargrass Creek, basin in Metropolitan Louisville, Kentucky. The analysis conducted for Beargrass Creek was a feasibility level study. The Final Feasibility Report was completed in September 1997. In addition to the discussion of Beargrass Creek, a synopsis of the Louisville District's experiences with risk based analysis for a Continuing Authority study conducted under Section 205 of the 1948 Flood Control Act, and a 905(b) analysis, are presented.

The Louisville District's involvement with risk-based analysis for flood damage reduction studies began in January 1993, with the Indianapolis North, IN, Feasibility Study, which focused on the rehabilitation of existing levees and new levee construction. This was the first study conducted in the Louisville District where the concept of freeboard was not applied. At the time the Indianapolis North Feasibility Study was initiated, the District had little experience with using a risked-based analysis for flood damage reduction studies, and had several questions concerning the value added. Initial thinking was that the risk based analysis approach would require significantly more time, cost, and effort by the study team. The non-Federal sponsor for the Indianapolis North study, though supportive of the use of a risk-based analysis, expressed concern about potential increases in study cost. It appeared that, for the economist, a significant learning curve would be required to apply the risk-based approach. Some reluctance was due to the fact that the Louisville District had invested heavily in training at the Corps' Hydrologic Engineering Center (HEC) in the use of the Flood Damage Analysis (FDA) software. Beginning in the late 70's until the early 90's this was the economist's primary tool for flood damage analysis. Programs which were a part of the FDA package, such as EAD, SID, FDA2PO and other utilities were well documented, and supported by HEC.

Expertise was sought from the Hydrologic Engineering Center (HEC) and the Institute for Water Resources (IWR). Initially, a version of the @Risk spreadsheet which produced a stage-damage relationship with uncertainty was used for the analysis. Assistance was provided by IWR staff in developing probability distributions of the results of the risk based analysis. This occurred prior to the release of the Beta Test version of the FDA program now used by the District. Knowledge gained through application of the risk based analysis approach to the Indianapolis North Feasibility Study, was soon applied to other District flood damage analyses, such as Beargrass Creek, KY.

At present, based on it's success with studies such as Indianapolis North, the provisional, or Beta Test version of the HEC-FDA software is the Louisville District's primary tool for risk-based flood damage analysis for all studies. The HEC-FDA is now used by the District for all stages of study, from initial assessments, and 905(b) analyses, to feasibility level studies. Since the Indianapolis North study, the Louisville District has used a risk-based analysis approach for a total of nineteen studies.

The Louisville District has used risk-based analysis for Initial Assessments, as well as for more detailed decision documents. Current policy guidance requires a risk-based analysis only for decision documents. However, because the new release of the HEC-FDA is so efficient at handling the data input and interfaces between hydrologic engineering and economics, it makes sense to assess the uncertainties as early as possible, during the initial appraisal, or, if data is available, during conduct of the 905(b) analysis.

To date the HEC-FDA has been used for urban and agricultural studies, to evaluate the uncertainties inherent in the effectiveness of levees, detention basins, and channel modifications, stream diversion, and combinations of these structural alternatives. Risk-based analysis has also been used for an evaluation involving a major rehabilitation of a Corps of Engineers multipurpose reservoir. For this particular analysis, an event tree was developed to identify the probabilities and uncertainty associated with various failure modes. The probabilities of failure were used in the economic analysis to determine the impact on project outputs such as flood damage reduction, water supply, and recreation. The event tree was jointly developed by senior members of the study team, including geotechnical and hydraulic engineers, and economists.

Risk based analyses using the new program are routinely conducted for Continuing Authority Program studies conducted under Section 205, as well as expedited reconnaissance studies conducted under Section 905(b) of the Water Resources Development Act of 1996. The Lebanon Junction, Kentucky Section 205 study, and the Mill Creek, Kentucky, 905(b) analysis are two examples, and are discussed later in the paper.

Beargrass Creek, KY Feasibility Study

The Beargrass Creek feasibility study was conducted in partnership with the Louisville and Jefferson County Metropolitan Sewer District (MSD). MSD is responsible for the maintenance and improvement of storm water drainage facilities in Jefferson County, Kentucky.

The Beargrass Creek basin encompasses approximately 61 square miles. Approximately 50% of the City of Louisville, the largest city in the state, lies within the boundaries of the drainage area. Figure 1 depicts the drainage basin boundaries. Beargrass Creek originates in eastern Jefferson County, and flows through the north-central part of the county, into the Ohio River just east of Louisville's downtown business district. The South Fork, which is about 15 miles in length is considered the main stem. The Middle Fork tributary, also 15 miles in length, joins the South Fork about 1.5 miles above its mouth in downtown Louisville. Muddy Fork, approximately half the size of the other two streams, also joins the South Fork in downtown

Louisville, about one-half mile above its mouth. The feasibility study focused on the southern half of the Beargrass Creek drainage basin, where both the South Fork, and its tributary Buechel Branch, are located. The South Fork has one gaging station, located at stream mile 6.6. Buechel Branch is ungaged. For study purposes, the study area on South Fork was divided into 15 reaches, and Buechel Branch was divided into six reaches.

The Beargrass Creek basin is located in a highly developed area. The population approaches 2,500 people per square mile. Residences and businesses are built adjacent to the stream, particularly in the lower reaches. There are many multiple family residences within the study area. Parts of nineteen apartment complexes have buildings in the floodplain which are subject to flooding.

Development in the last two decades, particularly in the upper reaches of South Fork has resulted in additional rainfall run-off, and a corresponding increase in potential damage. The amount of development and hydrologic characteristics of the watershed are not expected to change significantly in the future.

Flooding from Beargrass Creek is among the top priority problem areas within Jefferson County. Flooding occurred in the basin in 1937, 1964, 1970, 1973, 1990, and in 1997. The flood of record is the March 1964 event, which resulted in the greatest 24 hour rainfall ever recorded in Louisville up to that point, 6.97 inches. Flooding from Beargrass Creek is caused by locally intense rainstorms. Flood waters from the streams generally rise rapidly, with little warning time, and have high velocities. In the upper reaches of the South Fork, the duration of flooding is generally between 25-45 minutes, once the water is out of bank. Expected depths of flooding on first floors of structures for a 1% chance event range up to 8.5' on South Fork and 3.1' on Buechel Branch.

Approximately 85% of the structures in the study area are residential. A 1% chance flood event along the South Fork would damage 759 structures, valued at $219,123,000, and would result in about $45,590,000 in damages. On Buechel Branch, a 1% chance flood would affect about 170 structures valued at $15,286,000, and would cause damage estimated at $2,812,000. A 10% chance flood would cause an estimated $6,803,000 in total damages on South Fork, and $890,000 on Buechel Branch. The expected annual damages (EAD) for the study area are $3,015,000.

Economic Analysis—Evaluation Tools.

Estimates of flood damages were based on surveys originally made during the 1993 Reconnaissance Study, and later updated for the Feasibility Study. Two different Flood Damage Analysis (FDA) packages were used to evaluate damages and benefits of proposed flood mitigation plans during the course of the study. During the early stages of the study, the Beta Test Version (NextGen) of the FDA software had not been widely released to the field for use. Therefore, the FDA package of computer programs developed in 1994 by the Corps' Hydrologic Engineering Center (HEC) was used to integrate hydrologic, hydraulic and economic data, and to compile initial screening level estimates of potential damage due to flooding. The 1994 version

to show areas and structures subject to flooding. First floor elevations of structures within the study area were estimated from the topography and spot elevations of the mapping.

The first floor elevations of a sample of 195 structures were verified by the District's Engineering Division, using land surveying instruments. The sample equated to 16% of the number of structures in the 0.2% chance floodplain. Elevations of the specific structures obtained using survey instruments were then used in the economic modeling, instead of the estimated values. The average of the absolute values of the differences between the estimated and surveyed first floor elevations for this sample was 0.62'.

Depth-Damage Estimates. Interviews were conducted with responsible parties for each non-residential property within the 1.0% chance floodplain, and for the larger properties located between the 1.0% and 0.2% floodplains. The damage estimates for non-residential categories reflected the high and low range of damages as well as the most likely damage for various levels of flooding, up to the depth of the 0.2% chance flood. This triangular distribution is not an active option for the economic portion of the current version of the FDA software, therefore, a method described in the draft Engineering Manual (EM) 1110-2-1619, dated March 1996, was used to estimate standard deviations of error for the damage estimates. This method takes into account the range between the maximum and minimum estimates of damage and assumes a normal distribution, and a 95% confidence interval.

Residential damage estimates were based on the Federal Emergency Management Agency's (FEMA) depth-damage functions (expressed as a percent) for structure and contents for various depths of flooding. The percent damage functions were first developed by the Corps of Engineers in 1973, and since 1978, have been updated by FEMA based on flood damage claims data. The dispersion statistics as measures of error in the residential damage functions are only available for actual claims data collected. Some structure types have the required number of claims needed for full credibility in the damage estimate at certain depths of flooding. For these estimates, the calculated standard deviation of error is equivalent to that for the depth-percent damage function used. However, values for most flood depths in the damage functions for the various structure types do not have sufficient claims data to achieve full credibility. In these cases, the standard deviation which was calculated for the actual claims data was still applied, because it was the closest proxy for this statistic for the values used.

Content and Structure Value. The Marshall & Swift Residential Cost Handbook was used to estimate the value of flood prone residential structures, both single and multi-family, in the study area. Estimates of error in values of residential structures were based on a range of typical accuracy provided by a representative of Marshall & Swift in a previous feasibility study. The content-to-structure value ratios used with the new FDA program are those provided for various structure types in EM 1110-2-1619. These are based on FEMA Flood Insurance Administration (FIA) claims data. Using this data, contents, as a percentage of structure value, range from 40.2% to 44.1%. Standard deviations of error were also provided in the EM for these ratios, and were used in this model.

Existing Condition Damages. The new FDA program uses the length of record of the gage, 56 years on South Fork, to calculate the standard deviations of error for exceedance probability-discharge relationships for hydrologic uncertainty. The hydraulic stage-discharge uncertainty was estimated to become constant at the 1.0% chance flood, at a standard deviation of error of 0.5'.

Existing condition flood damage, estimated with the new FDA program, with uncertainties of the major economic and hydrologic and hydraulic variables accounted for, is shown in Table 2.

TABLE 2

Beargrass Creek Feasibility Study
Existing Condition Flood Damage ($000)
By Category and Flood Event
(With Uncertainties Accounted For)
FY 1996 Price Levels

	Flood Event by Chance of Occurrence							
Stream/Reach/Category	100%	50%	20%	10%	4%	2%	1%	0.2%
South Fork								
Single Family Residential	19	108	862	2,379	3,889	6,678	8,985	14,771
Multi Family Residential	113	302	1,747	4,530	7,118	11,966	16,152	27,575
Commercial	26	65	283	665	1,247	8,628	17,728	42,062
Public	0	1	68	969	2,040	3,706	4,435	5,775
Roads/ Utilities	0	0	4	13	22	49	77	151
Automobile	5	22	306	813	1,305	2,669	4,222	9,144
Emergency Costs	3	7	44	115	181	360	537	1,027
Traffic Diversion	0	1	6	19	33	62	86	160
Total	166	506	3,320	9,500	15,835	34,118	52,222	100,665
Buechel Branch								
Single Family Residential	5	18	107	418	777	1,278	1,586	2,102
Multi Family Residential	17	94	405	639	761	922	1,023	1,184
Commercial	0	1	13	21	28	42	55	82
Public	1	2	5	14	21	28	31	36
Roads/ Utilities	0	0	0	0	0	0	0	0
Automobile	1	5	20	30	35	43	47	55
Emergency Costs	0	2	12	33	53	83	104	140
Traffic Diversion	1	7	38	84	127	190	230	296
Total	25	128	600	1,239	1,803	2,586	3,076	3,895

Note that damage estimated when including uncertainties oftentimes begins in different flood zones than when estimated without uncertainties accounted for, as with the original FDA software. Uncertainties in first floor stages of structures and in hydrologic frequency curves and rating curves often indicate the possibility of damage at more frequent events. The total expected annual damage estimate, with uncertainties estimated using the Beta Test program was higher than that of the original FDA software. This difference in EAD estimated with the newer release program and with the original FDA software was also noted in other flood damage analyses conducted by the District.

Evaluation of Flood Reduction Plans. During the screening process, a number of flood damage reduction measures were evaluated. Those that were studied included: Without Project Condition/No Action, Reservoirs, Detention Basins, Channel Modification, Levees and Floodwalls, and Bridge Modifications. As stated, economic evaluation was performed with risk and uncertainty analysis with the Beta Test program beginning with the screening of the final array of plans.

The current FDA program requires eight water surface profiles. Prior to receipt of the software, hydrologic information was supplied for flood events with exceedance frequency values of 50%, 20%, 10%, 4%, 2%, 1% and 0.2% chance of occurrence. Because of the requirements of the current program, the H&H analysis for the last nine flood damage reduction plans evaluated included hydrologic information for the 100% chance flood profile. The final nine plans were evaluated with both FDA programs, with and without uncertainties considered. When this was done, the size and design which yielded maximum net benefits for two of the major project components, a detention basin, and channel modification, was the same with both programs. The inclusion of uncertainties in the analysis did not change formulation for these components.

The recommended plan consisted of ten components, eight of which are detention basins. An I-Wall/Levee, and channel modification are also part of the recommended plan. A summary of residual damage, estimated with the EAD program, and percent reduction of damage with the NED plan, is presented in Table 3, and is also shown with uncertainties accounted for in Table 4.

TABLE 3

Beargrass Creek Feasibility Study
Expected Annual Damage and Benefits
With and Without NED Plan
FY 1996 Price Levels ($000)

Stream	Expected Annual Damage Without Plan	With Plan	Benefits	Percent Reduced
South Fork	2,705	844	1,861	68.8%
Buechel Branch	310	93	217	79.0%
Total Study Area	3,015	937	2,078	68.9%

Note: Expected annual damage and benefits shown were estimated with the EAD program, not accounting for uncertaintie

TABLE 4

Beargrass Creek Feasibility Study
Expected Annual Damage and Benefits
With and Without NED Plan
(With Uncertainties Accounted For)
FY 1996 Price Levels ($000)

Stream	Expected Annual Damage Without Plan	With Plan	Benefits	Percent Reduced
South Fork	3,587	1,572	2,015	56.2%
Buechel Branch	411	112	299	72.7%
Total Study Area	3,998	1,684	2,314	57.9%

Note: Expected annual damage and benefits shown were estimated with the NextGen FDA program, which accounts for uncertainties.

Table 5 presents expected values with associated probabilities for expected annual benefits, net benefits, and benefit-to-cost ratios for the recommended NED plan.

Table 5

Beargrass Creek Feasibility Study
Economic Analysis With
With Recommended NED Plan
FY 1996 Price Levels ($000)

Probability of Value	Expected Annual Benefit Exceeds	Net Benefit Exceeds	Benefit-to-Cost Ratio Exceeds
Expected	2,314	1,504	2.86
0.75	1,365	555	1.69
0.50	2,071	1,261	2.56
0.25	3,054	2,244	3.77

Lebanon Junction, Kentucky

Lebanon Junction, Kentucky is located in southern Bullitt County about 25 miles from Louisville, and is shown in Figure 2. A levee was constructed by the Corps in 1966 to reduce frequent flooding from the Rolling Fork river. The existing project consists of a 4,175' long earth levee constructed to an elevation of 450' msl, with three drainage structures. Since the levee was constructed, Lebanon Junction has been flooded four times. Flooding occurred as a result of flow entering the town at the low area, where the top of the levee is elevation 447' msl.

A Draft Detailed Project Report was prepared in 1990 to report the findings of a feasibility level evaluation of increasing the level of protection provided by the existing project. The Recommended Plan at that time, consisted of raising the existing levee to elevation 451. Due to lack of local sponsor funding the feasibility study was suspended in 1990. The feasibility study was resumed in 1996. The initial focus of the study was on re-evaluation of the 1990 plan. In March 1997, a storm entered the Louisville area which exceeded rainfall records. Former record rainfall of 7-8 inches was surpassed with 12-13 inches of rainfall in a 24-30 hour period. The storm affected the Lebanon Junction study area. Until March 1997, floodwaters had not been recorded above elevation 451' msl in Lebanon Junction. As a result of the March 1997 event, the existing levee was overtopped. High water marks were recorded at elevation 452' msl. As a result of the flood, the design of the recommended plan, this time based on a risk based analysis, was changed to increase the effective levee protection to elevation 453'.

The 1990 study was not conducted using a risk-based analysis. The levee was designed using the concept of freeboard. The current analysis, with the new HEC-FDA utilized some of the original economic study data, and incorporated risk and uncertainty. Table 8 presents output from the new HEC-FDA related to the project performance. As can be observed from Table 6, the Recommended Plan still has considerable long term risk. However site constraints preclude the levee height exceeding elevation 453'.

The risk associated with the proposed levee being overtopped was presented to the mayor and community in September 1997. Data from Table 6 was used to brief the City on the risk associated with project performance. The City of Lebanon Junction has to date indicated a continued interest in participating in construction of the $1.3 million dollar project to upgrade the existing levee.

Mill Creek, Kentucky.

The Mill Creek, Kentucky expedited reconnaissance study is an example of an analysis conducted under the 905(b) guidance. The Mill Creek study area is in the southwest portion of Jefferson County, in metropolitan Louisville, Kentucky (see Figure 3). The economic analysis was conducted in about two weeks at a cost of approximately $3,000, and used the current FDA software. Because of the efficiency of using the current program, the District made the decision to used a risk based approach whenever possible. In the case of Mill Creek, existing Geographic Information System (GIS) data was available from the local sponsor, and was easily interfaced

Table 6

Expected Annual Performance and Equivalent Long-term Risk With Existing and Proposed Options Lebanon Junction Kentucky Rolling Fork

		Equivalent Long-term Risk Chance of Exceedance during		
Levee Plan	Annual Chance of Design Being Exceeded	10 Years	25 Years	50 Years
Existing Levee	11.6%	71.0%	95.5%	99.8%
Option 1(451')	3.4%	29.4%	58.1%	82.5%
Option 2(453')	1.9%	17.4%	37.9%	61.4%
Option 3(454')	1.4%	13.0%	29.4%	50.2%
457.8	0.3%	2.6%	6.4%	12.3%

with the FDA program. GIS data, including addresses, structure locations by stream mile, structure value, property type and other information was provided. There were about 800 structures in the 1% chance flood with expected annual damages of over $600,000. The 905(b) analysis was recently approved as a basis for developing the Project Study Plan.

Conclusion. These three studies represent a diverse spectrum of effort, from an expedited reconnaissance level investigation, to a General Investigation Feasibility Study with multiple flood damage reduction alternatives. In each instance, the incremental cost for conducting the risk based analysis was minimal. The economic analysis for a Section 205 Study generally accounts for about 10-15% of the total study cost. That percentage is very comparable to the cost of the evaluation before the requirement for conducting the risk based analysis.

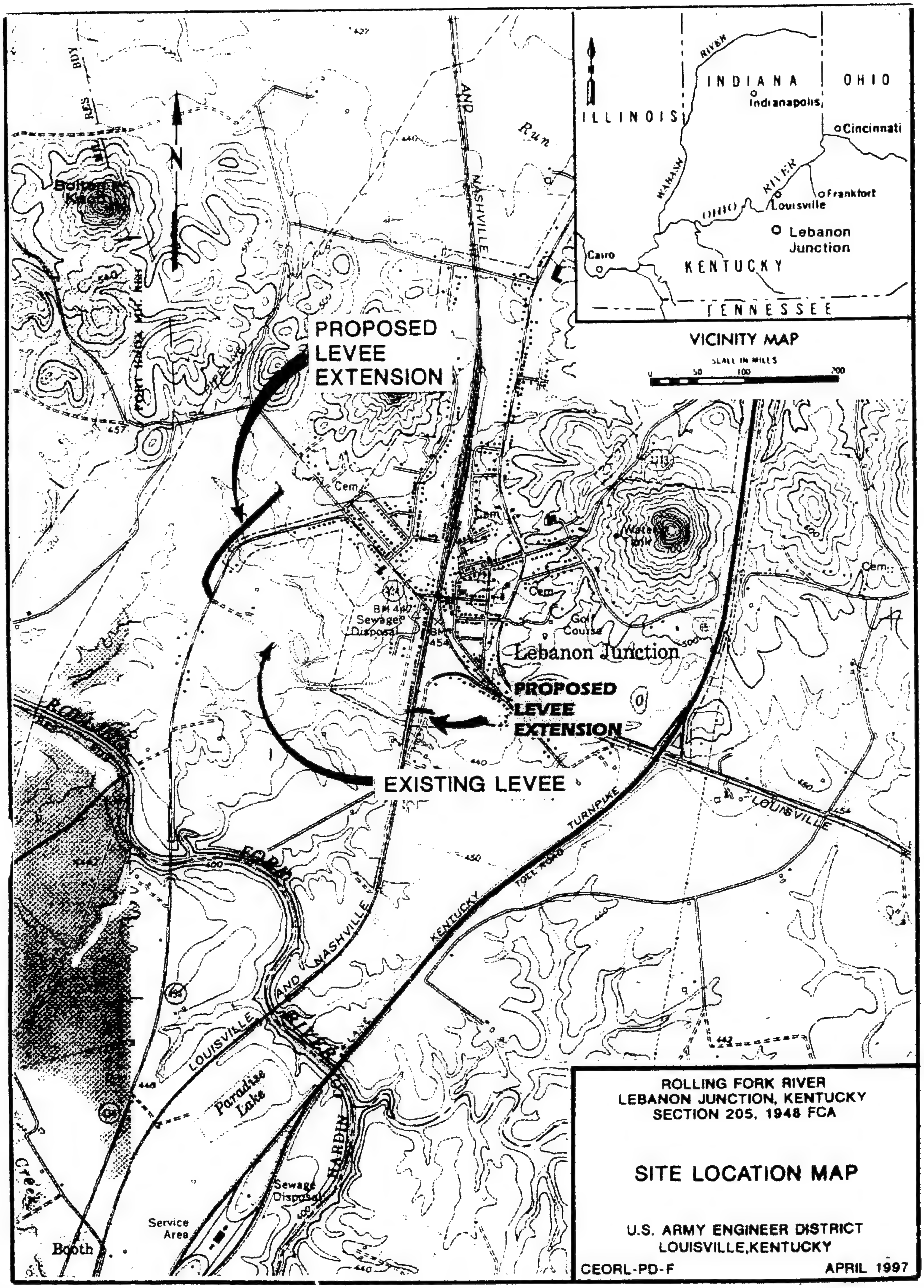
Fortunately the Louisville District has gained experience in preparing reports including a risk-based analysis, and can focus less on the mechanics of using the software, and more on gathering data in a risk-based framework. Experiences with the original FDA software has highlighted the importance of communication and close coordination with other disciplines on the team, primarily Hydrology and Hydraulics and Geotechnical Engineering. Continued coordination with HEC on application of the software is also critical. The challenge lies in interpreting the results and conveying them in a meaningful manner to the project sponsors, and affected public. Table 7 presents the listing of the nineteen flood damage reduction studies conducted by the Louisville District using risk based analysis.

Table7

Risk-based Analysis
By the Louisville District

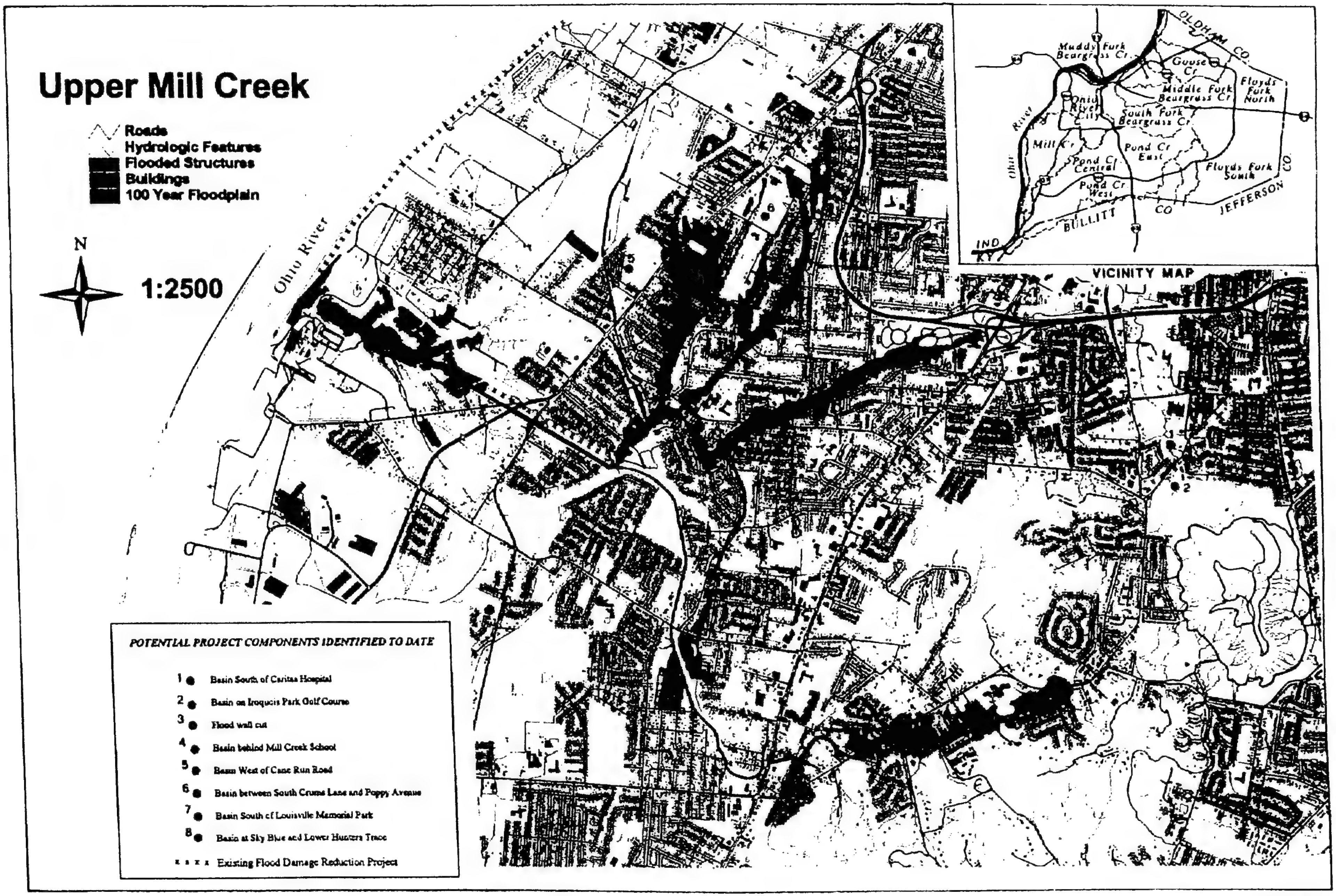
Index	Study Name	Project Feature	Study Area/Type	Latest Study Report	Date of Study	Project Status	Risk-based Software/Other
1	Rushville, IN	Levee	Urban/CAP	Feasibility/Positive	May-96	P&S	HEC and IWR @Risk Spreadsheets
2	SW Louisville Ky	Combined Sewer/Ponding	Urban/GI	Reconnaissance/Positive	May-96	Begin FR Jan 98?	SWMM/GIS/NextGen HEC-FDA for FR
3	Metro Indianapolis	Rehabiltate/Raise Existing Levee	Urban/GI	Feasibility/Positive	Sep-96	Start FY98	HEC and IWR @Risk Spreadsheets
4	Silver Grove, Ky	Levee	Urban/CAP	Initial Assessment	Sep-96	Awaiting Approval	NextGen HEC-FDA
5	Gunpowder Creek, Ky	Detention Structures	Urban/CAP	Initial Assessment/Negative	Sep-96	Provide Tech Assist.	NextGen HEC-FDA
6	Jackson, KY	Stream diversion	Urban/CAP	Feasibility/Positive	Oct-96	P&S/RE Aquisition	HEC and IWR @Risk Spreadsheets
7	Mill Creek Ky	DetentionStructures & Channel Mod.	Urban/GI	905b/Positive	Aug-97	Awaiting Approval	NextGen HEC-FDA/GIS
8	Patoka Lake	Spillway Repair of USCE Lake	Major Rehab	Major Rehab	Sep-97	P&S/FY98	Event Tree
9	Beargrass Creek	Detention/Levee/Channel Mod.	Urban/GI	Feasibility/Positive	Oct-97	In Review	NextGen HEC-FDA
10	Birds, ILL	Levee	Urban/CAP	Initial Assessment/Positive	Sep-97	Awaiting Approval	NextGen HEC-FDA
11	Bridgeport, ILL	Channel Modification	Urban/CAP	Initial Assessment/Negative	Sep-97	Completed	NextGen HEC-FDA
12	Sumner, ILL	Channel Modification	Urban/CAP	Initial Assessment/Negative	Sep-97	Completed	NextGen HEC-FDA
13	Stanford, Ky	DetentionStructures & Channel Mod.	Urban/CAP	Initial Assessment/Positive	Sep-97	Awaiting Approval	NextGen HEC-FDA
14	Panther Creek KY	Detention Structures	Agriculture-Urban/GI	905b/Positive	Aug-97	Awaiting Approval	Lotus Spreadsheet/NextGen HEC-FDA
15	Anderson IN	Rehabiltate/Raise Existing Levee	Urban/CAP	Initial Assessment	Aug-97	Awaiting Approval	NextGen HEC-FDA
16	Mill Creek OH	Levees/Channel Modification	Urban/GI	GRR	Oct-97	Awaiting Funding	NextGen HEC-FDA/GIS
17	Lebanon Junction Ky	Rehabiltate/Raise Existing Levee	Urban/CAP	Feasibility/Positive	Nov-97	Ongoing	NextGen HEC-FDA
18	Lexington, KY	Channel Modification	Urban/GI	Reconnaissance/Positive	May-97	In Review	NextGen HEC-FDA
19	Greenfield Bayou	Rehabiltate/Raise Existing Levee	Agriculture/GI	Feasibility/Negative 1/	Apr-98	Ongoing	@Risk Spreadsheet/NextGen HEC-FDA

1/ Positive Environmnetal Restoration Feature



INDIANA
OHIO
Indianapolis
ILLINOIS
Cincinnati
RIVER
WABASH
OHIO
Frankfort
Louisville
Lebanon Junction
Cairo
KENTUCKY
TENNESSEE
VICINITY MAP
SCALE IN MILES
0 50 100 200
PROPOSED LEVEE EXTENSION
Run
NASHVILLE
Cem
Water Tank
Cem.
Sewage Disposal
Golf Course
Lebanon Junction
PROPOSED LEVEE EXTENSION
EXISTING LEVEE
LOUISVILLE
TURNPIKE
TOLL ROAD
KENTUCKY
LOUISVILLE AND NASHVILLE
FORK
RIVER
Paradise Lake
HARDIN
Sewage Disposal
Service Area
Booth
Creek
ROLLING FORK RIVER
LEBANON JUNCTION, KENTUCKY
SECTION 205, 1948 FCA
SITE LOCATION MAP
U.S. ARMY ENGINEER DISTRICT
LOUISVILLE,KENTUCKY
CEORL-PD-F
APRIL 1997

Figure 1



Upper Mill Creek
Roads
Hydrologic Features
Flooded Structures
Buildings
100 Year Floodplain
N
1:2500
Ohio River
VICINITY MAP
Muddy Fork Beargrass Cr.
Goose Cr.
Middle Fork Beargrass Cr.
Floyds Fork North
Ohio River City
South Fork Beargrass Cr.
Mill Cr.
Pond Cr. East
Pond Cr. Central
Pond Cr. West
Floyds Fork South
OLDHAM CO.
JEFFERSON CO.
BULLITT CO
IND
KY
POTENTIAL PROJECT COMPONENTS IDENTIFIED TO DATE
1 Basin South of Caritas Hospital
2 Basin on Iroquois Park Golf Course
3 Flood wall cut
4 Basin behind Mill Creek School
5 Basin West of Cane Run Road
6 Basin between South Crums Lane and Poppy Avenue
7 Basin South of Louisville Memorial Park
8 Basin at Sky Blue and Lower Hunters Trace
x x x x Existing Flood Damage Reduction Project

Figure 2

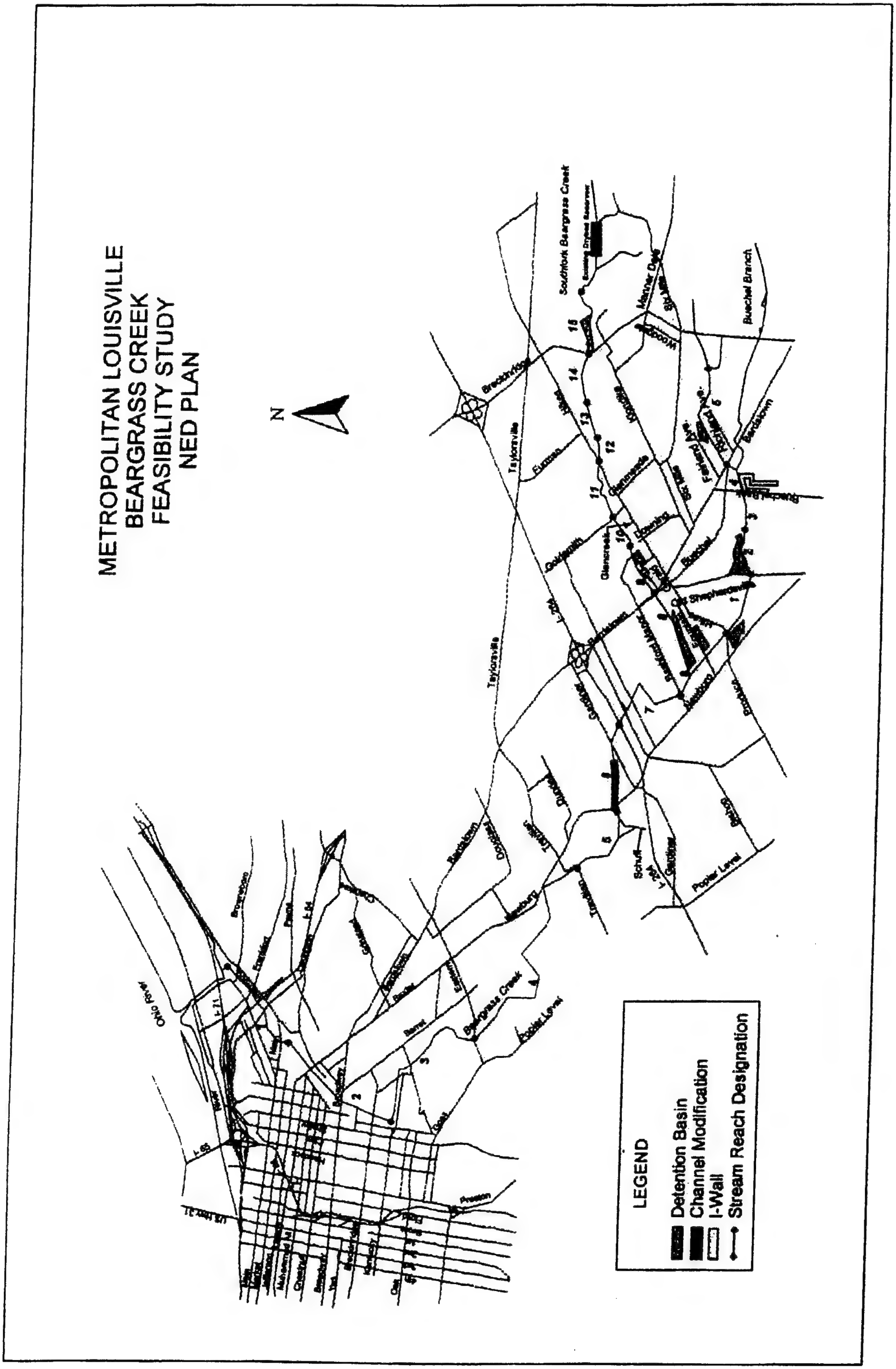

METROPOLITAN LOUISVILLE
BEARGRASS CREEK
FEASIBILITY STUDY
NED PLAN
N
LEGEND
Detention Basin
Channel Modification
I-Wall
Stream Reach Designation
Ohio River
I-71
I-65
I-64
Beargrass Creek
Poplar Level
Taylorsville
Breckinridge
Goldsmith
Bardstown
Southfork Beargrass Creek
Buechel Branch
Preston

Figure 3

COMMUNICATION OF FLOOD-RISK INFORMATION

by

Arlen D. Feldman[1] and H. James Owen[2]

SUMMARY

Measures for flood loss reduction are often costly and/or restrictive. The local officials and general public making up a community are not likely to agree on or approve such measures unless they understand the need for them and believe that the economic and other benefits outweigh the costs and associated negative aspects of the measure.

Public participation in planning and rational consideration and approval of proposed projects depends on understanding of the flood risk, alternatives for action, related environmental and economic considerations, and other aspects of proposed projects. Proposals are likely to be deferred or rejected if the engineers, planners and other technical specialists fail to convey these kinds of information in a fashion that is easily understandable to the non-professional. In order to improve the acceptability of their work, technical specialists must use plain English and diligently explain concepts and procedures.

Previous research concerning the extent to which local officials and the public understand terminology related to floodplain management indicated that their level of understanding is generally low. However, review of the literature related to risk communication suggested that some ways existed to make reports and presentations easier to understand.

A case study was undertaken to verify and expand knowledge of the problem by testing the level of understanding of local officials and the public concerned with an actual project. The American River Study being conducted at that time by the Sacramento District office of the Corps of Engineers was chosen for the case study because of its convenient location, stage of the study, keen local interest in the outcome of the study, and its typical nature.

This paper describes lessons learned from a review of the literature and a case study focusing on the success with which the public participation program was carried out in the American River Study. It presents conclusions and recommendations thought to be applicable to public participation elements of other projects.

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[1] Chief, Research Division, Hydrologic Engineering Center, HEC

[2] Consultant to HEC who performed most of the research represented in this paper. Jim passed away in January 1997; this paper is dedicated to his memory.

INTRODUCTION

Risk communication usually involves providing information about: the existence and seriousness of a threat; and steps that can be take to reduce or eliminate the threat. The purpose of the risk communication may be limited to providing a basis for decision making or go further and encompass efforts to persuade people to take some recommended action.

Risk communication in the field of flood loss reduction is often complex for several reasons.

- The risk is probabilistic.
- Numerous alternatives for reducing risk are usually apparent or can be developed, each of which can often be implemented in different ways and to different degrees, and many of which can be used in various combinations with one another.
- The alternatives that may be used for reducing risk often differ radically in the nature and amount of their costs and benefits.
- Many of the available alternatives are multi-purpose in nature and require parallel consideration of the needs for and benefits of water supply, electric power generation, and other functions.
- Alternatives often have significant environmental impacts, broad-scale economic impacts, and others that can not be quantified for easy comparison and consideration.

In addition, communication of information about flood risks and steps that might be taken to mitigate the risk is handicapped by a generally low level of understanding on the part of public officials and the general public concerning the basic technical facts about flooding. These include: the major causes and types of flooding; the relationship between flood magnitudes and frequency; the concept of a floodway including such notions as the floodway and flood fringe; and the reality that severe floods can occur in most areas.

Such misconceptions and lack of information about flooding and the degree of flood risk make it difficult for people to appreciate the importance of solving flood problems. The result often is a failure to take any action at all until a damaging flood makes the risk obvious. Even then, lack of understanding of the nature of flooding makes it difficult for people to rationally consider solutions that might be suggested. As a result of the public's lack of understanding of flood risk, needed programs and projects are often delayed for years or not implemented at all, contributing significantly to flood losses.

William Ruckelshaus presented the following excellent summary of the communication problem in his "The Center's Tenth Anniversary" observations in the Newsletter of the Center for Risk Management (Spring 1997).

> *...Our ability in the future to effectively communicate information about risks, and to successfully involve the public in the process of controlling them, will determine our progress in managing those risks in a sensible manner. Experience to date tells us we have a long way to go.*
>
> *For just as we know more about potential risks today than we did ten years ago, we also have continued to vest in our citizens the power to say "no." That power is an awesome responsibility in our democracy and one that demands of our citizens much attention, if it is to be exercised with care.*
>
> *We have learned that the willingness of people to say "no" will not disappear just because it is inconvenient or messy to the rest of society. The responsibility of informing the public as it participates in the process of controlling risk now becomes an even greater task. It is toward this task that the center has dedicated much of its effort.*
>
> *We have made strides in risk characterization and risk communication over the last ten years. But much more needs to be done. The challenge of successfully involving the public in tough and ever more complex risk management decisions will be one measure of our success in the years ahead. One reason for this is that accomplishing meaningful public involvements is essential to restoring trust in the institutions of our government. Nothing has so defined the past three decades of growing environmental awareness and action than a parallel decline in public faith in government. Reversing this decline is then essential for a successful democracy.*
>
> *Demonstrating our ability to address environmental problems in the context of free institutions will help reassert our traditional international environmental leadership at a time when the developing world is ramping up its economic growth. The environmental impact of the inevitable development in the Third World can hardly be imagined if it follows the path that the developed nations have already taken.*
>
> *One hopeful sign is emerging. We are seeing the growth of efforts to deal with development problems through consensus-based, collaborative decision-making processes in the United States - particularly in the West. These efforts have so far concentrated on natural resource and environmental issues. By one count, over sixty basin or watershed efforts are now under way in the Colorado River drainage alone. It is essential to understand that each of these efforts is unique to the problems, the locale, even the personalities involved. This approach is not something you can stamp out with a cookie cutter. Yet it has met with some preliminary successes: the Clark Fork River in Montana and the Old Growth Forest Commission in Washington State are cases in point.*
>
> *Such cooperative decision-making processes are by no means panaceas for every environmental problem. They are extremely difficult to bring off,*

frustrating to participate in, often lengthy and grueling for their members, and they can easily fail. They can fail, for example, when short-term economic interests overwhelm all other factors or when one party believes it can get a better deal elsewhere. But they are an important start that needs to be encouraged and nurtured.

Thomas Jefferson once pointed out that if the people appeared not enlightened enough to exercise their control of government, the solution was not to take away the control but to "inform their discretion by education." The collaborative processes that are springing up around the country are doing just that, giving to large numbers of citizens new comprehension of the complexity involved in government decisions, out of which has to come a heightened appreciation of, and tolerance for, the necessary work of government...

RISK-COMMUNICATION RESEARCH

Research into the field of risk communication as it relates to flood loss reduction was undertaken by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers beginning in 1988. The overall objective of the research was to improve the presentation of flood risk information in the agency's dealings with communities and individuals. Three major activities were undertaken: 1) survey of the literature and preparation of a document on explaining flood risk; 2) collection and analysis of informational materials currently in use; and 3) conduct of case study.

Literature review. The first activity undertaken was a general survey of the literature related to risk communication and summarization of what experts in that newly emerging field had to say about what works and what either doesn't work or might even be counterproductive. That part of the research led to preparation of a brief summary of the literature and a brochure about the basic techniques of risk communication. The best references found at the time were noted in Engineering Pamphlet, EP 1110-2-8, "Explaining Flood Risk," developed by HEC in 1992.

Since that literature review, risk-communication-problems awareness has received much attention. In 1993, the Corps Institute for Water Resources, IWR, published a report entitled "Guidebook for Risk Perception and Communication in Water Resources Planing." In 1996, "Rx for Risk Communication" was published in ASCE's Civil Engineering magazine

Risk-Communication Materiels. The second activity of the research effort was collection of informational materials presently in use by states, the Corps of Engineers, and other federal agencies to explain flood risk. Twenty-one states and the Commonwealth of Puerto Rico responded to the request for example materials with a total of 94 items. Another 37 items were collected from Corps of Engineers offices and other federal agencies. Each of the 131 submitted items were reviewed to determine the extent to which they conveyed information intended to help the reader understand the basic facts about flood risk. The evaluation found that few materials were in use which provided rudimentary information about flood risk in a manner that

was easy to understand. The conclusion of the investigation was that some improved educational tools were clearly needed if the public's poor understanding of flood risk is the be improved.

It is apparent that one reason why the general public is uninformed about flood risk is the small number and nature of the materials that have been made available to inform them. Probably only a small percentage of the population has seen anything relating to flood risk and what they have seen tends to be limited to a perfunctory, rather dull and impersonal description of the amount of national or state flood losses. Only three of the items reviewed attempted to personalize the concept of flood risk in easily understood terms such as by showing the probability of flooding over the life of a home mortgage and only one item demonstrated the possibility of large floods through a map showing the occurrence of large floods in the past.

Some appropriate educational tools are needed if the public's poor understanding of flood risk is to be improved. Informational materials explaining flood risk should be coordinated and consistent with one another. Some state an federal agencies share the same need for informational materials explaining flood risk, it would be most efficient if a single set of high quality materials were prepared and made available for common use.

Design of the informational materials should take advantage of information in the literature relating to risk communication with respect to the effectiveness of communication techniques. The following paragraphs summarize pertinent guidance form the literature.

1) <u>Risk communication must be free of jargon</u>. Every field makes use of a shorthand of specialized words that are meaningful to specialists in the field and enable quicker communications. However, non-specialists do not often understand these terms or only understand their barest meaning. Unfortunately, the use of jargon tends to be perceived by the lay person as an indication that the user really doesn't care enough to explain the information in an understandable way or, even worse, that the jargon is an intentional effort to suppress questions and/or cover up a lack of knowledge. It is important that any new educational tools use simple, easily understood language.

2) <u>There must be a consensus of opinion among experts</u>. Differences in expert opinion sometimes make risk communications ineffective. The public is generally willing to concede that specialists in a field have detailed knowledge beyond that generally possessed and are willing to put some trust in the experts' viewpoints. However, the public expects that several experts armed with the same set of basic facts will come to the same conclusions and offer more or less the same recommendations. The risk communication tools that are developed should be based on facts generally accepted by the overwhelming majority of knowledgeable floodplain managers.

3) <u>The material and the source of the material must be credible</u>. Members of the public often lack the knowledge and experience needed to interpret many of the facts related to risk or to put them into a proper perspective. They are forced to rely on the expert for those insights and the extent that they do so depends on the credibility of the expert. Credibility is a function of

several factors such as past performance, openness, and apparent capability. It also depends on the public's perceptions about such things as 'hidden agenda' and 'axes to grind.' It is important that the views and materials making up the educational tools be attributed to respected and trusted sources and that the material be presented without bias.

4) The material must be tailored to the audience. The public is composed of individuals and groups that have different interests and priorities and which evaluate information according to their particular concerns. For some, flooding is of interest due to its economic impact. Others may be primarily concerned about its human dimensions. Still others may measure the potential seriousness of flooding according to its effect on the environment. In order to catch and hold the interest of such groups, the material must be couched in relevant terms, address the appropriate aspects of flooding, and make use of examples that are pertinent to the audience's special concerns.

5) The information should be personalized to the extent possible. It is important to personalize information on risk. It's one thing, for instance, for a person to see some figure for national or state flood losses and quite another to see what it means to their personal pocketbook, their personal safety, or their local economy. The public's strong interest in personalized information is apparent in the questions that are often asked at informational meetings dealing with risk such as "would you drink the water," "would you let your family live there," or "what are you doing about this problem."

6) Motivation should stress a positive approach and the possibility of success. Fear is a poor tool for motivating action. In fact, some studies indicate that the use of fear may occasionally backfire and lead to a hardening of existing positions and views rather than their modification. Allied to this is peoples' reluctance to attack problems that seem too large to be solved or appear beyond the control of the individual or community. Together, these lead to an attitude of resignation rather than to action. It is important that informational materials treat risk as one more fact of life to be dealt with and show that individuals and communities can have some control over the problem.

7) Data on risk must be presented in a meaningful way. An individual does not have an unlimited capacity to absorb and consider all of the information that is available on life's risks, even if it comes from a credible source and is presented in an interesting way. People typically sort out risk information by simply disregarding information about smaller risks on the basis that attention should be given to those events that are more likely to occur. One problem with this seemingly reasonable procedure is that people often fail to consider the seriousness of the consequences of an event along with its probability of occurrence. A second problem is that peoples' selection of what warrants concern is based on their personal perception of the probability of occurrence as opposed to whatever the actual probability may be. Studies show that peoples' perception of the probabilities of various risks has more to do with the nature of the risk than its statistical frequency of occurrence. In general, people tend to overestimate the rate of occurrence of events that are dramatic or unusual and therefore more newsworthy and underestimate the more commonplace risks. These kinds of errors lead to equating small

probabilities with zero probability and to a lack of concern with the relatively uninteresting problem of flooding.

One way of countering these problems is to present flood risk in a way that does not encourage dismissing it because of the small annual probability of a large flood. For example, the chance of flooding for particular property might be stated either as: a) a 30 percent chance of flooding over the life of a mortgage; b) a 10 percent chance of flooding over the next decade; c) a 1 percent chance of flooding in any particular year; or d) a 0.01 probability for any year. While all of the means of stating the risk might be equivalent, some are obviously more meaningful that others and more likely to make an impression to be remembered and perhaps stimulate interest in what can be done to reduce flooding. Whatever technical data and information are being presented should be presented in ways that are easily understandable and can be related to the experience of the members of the intended audiences.

Case Study. The third major activity was conduct of a case study focusing on the risk communication aspects of a major flood-related investigation by Corps of Engineers. The area selected for study was Sacramento, California. While several flood-related investigations were underway by the Corps for the Sacramento area, the case study focused on the American River Watershed Investigation.

The case study was conducted in two phases: Phase 1, initiating the study and doing the first round of participant interviews; and Phase 2, conducting the final participant interviews and preparing the final report. A summary of the case study report (HEC, 1992) is presented in the next section.

The objective of Phase 1 was to establish a baseline condition with respect to the level of understanding of flood-related matters against which the findings of the remainder of the study could be measured. The principal activities in Phase 1 were as follows.

- Reviewing materials relating to the District's work to become familiar with the studies underway and planned for the Sacramento area.

- Interviewing key District personnel to identify current attitudes and views of risk communication and their views as to the kinds of information needed by local decision makers.

- Identifying and interviewing a selected set of influential individuals concerned with solution of Sacramento's flood problem to determine their level of knowledge about the flood problem, constraints on planning, issues related to the solution of Sacramento's flood problems, concerns, perceived needs for information and other relevant points.

Phase 2 of the study provided for monitoring the remainder of the District's risk communication effort and preparing the final report. This included the following.

- Conducting final interviews with members of the selected set of influential individuals to assess whether and to what extent their views have been affected by the District's risk communication efforts, effectiveness of various types of informational efforts, and current concerns.

- Continuously monitoring the District's risk communication activities and related events including attending public meetings, collecting newspaper articles, etc.

- Conducting final interviews with key District personnel to identify changes in perceptions relating to risk communication over the course of the study.

- Comparison and analysis of results obtained from the interviews and testing of participants.

SACRAMENTO CASE STUDY

Due to its location on the floodplain at the junction of two major rivers, the Sacramento area has been subject to flood problems since its earliest development. Indian folklore and newspaper accounts mention at least nine major floods prior to 1900. Large floods subsequently occurred in 1904, 1907, 1909, 1955, 1964, 1969, 1970, 1982, 1986, and 1997.

Numerous small projects to alleviate flood risk were carried out in the Sacramento area in the late 1800's and the first half of this century. Through the 1950's and 1960's, planning and construction was underway on several major projects affecting flood risk to the expanding development in the Sacramento area. The extensive construction programs of this era, combined with the earlier private and public measures for flood protection and other purposes, have produced an extraordinarily complicated system for water management in the area. The chief measures and features include: Folsom Dam and Lake; Nimbus Dam and its reservoir, Lake Natoma; American River Levees; levees along the Natomas East Main Drainage Canal, etc.; Sacramento River weirs and the Sacramento Bypass and Yolo Bypass; various non-federal levees; numerous small upstream reservoirs in the American River; and floodgates operated by the City of Sacramento.

It was widely thought after construction of Folsom Dam that the dam and reservoir provided the Sacramento area adequate protection against flooding. Floods of 1955, 1964, 1969,1970 and 1982 were greatly reduced by the project. However, the flood of record which occurred in February of 1986 dispelled thoughts of safety from floods. Inflows to Folsom Reservoir during a several day period exceeded the design capacity, requiring releases greater than designed downstream channel capacities, and largely eliminating the project's ability to regulate flood flows. The record flows encroached into the levee freeboard at several locations,

causing severe erosion of levees at some places. A major disaster was averted by only a narrow margin.

Upon updating the flood frequency curve, the Corps of Engineers indicated that the February 1986 flood had an average annual exceedance frequency of only 65 to 75 years. The fact that the flow nearly overtopped the levees showed that the level of protection they provided was much lower than formerly believed. This new understanding of the flood threat caused a greater appreciation of the vulnerability of the area to flooding and sparked local interest in improved flood control. Interest in the investigation of improved flood protection for the Sacramento area was also spurred by considerations related to the flood insurance program. When mapping is completed for the area, premium rates for areas having less than a 100-year level of protection are due to rise steeply. In addition, further development of areas lacking a 100-year level of protection would be restricted by regulations required pursuant to the National Flood Insurance Program. Among others, these would limit new construction and require substantial improvements to existing structures to include protection from flooding.

<u>Identification of Case Study Participants</u>. It was estimated at the outset that the budget for Phase I of the case study would enable investigating the knowledge and views of about 20 individuals in addition to Corps staff. Several procedures were employed for selecting these participants.

Initially, representatives of several organizations making up the American River Watershed Investigation Executive Committee were asked to recommend a member of their organization's governing board as a case study participant. Since the objective of the case study depended on measuring a change in knowledge over time, it was asked that the recommended person be someone who was not actively engaged at that time in the American River Watershed Investigation. The persons suggested were contacted and asked to participate, resulting in the identification of 13 participants.

Sacramento District staff concerned with the American River Watershed Investigation were then asked to suggest the names of media representatives generally familiar with the flood problem and the American River Watershed Investigation. Contact was made with each of the suggested parties, leading to the identification of another three participants.

The selection of additional participants was then delayed pending the hearings held by Sacramento Area Flood Control Agency (SAFCA). Following the hearings, four individuals representing organizations expressing an interest in the study were asked to participate. Of the 20 persons originally agreeing to participate, only one eventually failed to provide the requested information at the initial round of interviews. The positions of the participants selected are shown below.

Director, American River Coalition
Director, American River Flood Control District

Director, State Reclamation Board
Director, Reclamation District 1001
Director, Sacramento Metropolitan Chamber of Commerce
Executive Director of a Sacramento area association of business interests
Executive Director of a statewide association of water-related agencies
Executive Director of a regional flood control organization
Member, Sacramento City Council
Reporter, Sacramento Union
Reporter, Sacramento Bee
Reporter, Channel 3 Television
Staff, California Department of Water Resources
Staff, Planning and Conservation League
Staff, county water resources agency
Supervisor, El Dorado County
Supervisor, Placer County
Supervisor, Sutter County
Supervisor, Yolo County

Findings of Participant Interviews. Participant interview forms were reviewed to assess the general level of information and knowledge exhibited by the participants. The results are described in the following sections. In each case, the results are for only the 11 participants that completed both the initial and final interviews. Results shown in brackets are for the second round of interviews.

1) Flood-Related Terminology. Participants in the case study were asked to indicate whether or not they understood the meaning of 53 terms, most of which were taken from reports concerning the American River Watershed Investigation that had been issued by the Sacramento District. All of the terms not taken from the District's reports were terms commonly used in the description of flood problems and flood loss reduction measures. Participants were not asked to demonstrate knowledge of their understanding so it was possible for them to falsely claim to know the meaning of any term.

On the average, participants indicated an understanding of 54 (72) percent of the terms. Individuals scores ranged from 18 [24] percent to 94 [88]. Table 1 lists some of the terms and the percentage of participants that indicated that they understood their meaning at the time of the initial and final interviews.

Table 1
Knowledge of Flood-Related Terminology

Term	Percent of Participants Understanding (Initial)	(Final)	Term	Percent of Participants Understanding (Initial)	(Final)
Ace-Foot	100	100	Peak Flood Stage	81	90
Backwater	36	72	Reconnaissance Study	81	90
Flood ins. rate map	90	90	Recurrence interval	45	63
Hydrograph	36	72	Spillway	72	90
Nonstructural measure	45	54	Stage-frequency curves	27	54

2) Key Terms. Participants in the case study were asked to demonstrate their knowledge of 10 key terms relating to floods and flood loss reduction through a two step process. First, they were asked to choose from among several meanings offered for a term and second, to indicate the level of confidence that they felt in having chosen the correct meaning. The participants averaged 60 [63] percent correct answers with a confidence level in the correctness of their answers of 54 [43] based on a scale of 0 being a pure guess and 100 being certainty of the correct answer. Table 2 lists some of those key terms and the percentage of correct answers and the average confidence level indicated for each term.

Table 2
Understanding of Key Terms

Term	Percent Correct (Initial)	(Final)	Level of Confidence (Initial)	(Final)
Flood probability	36	63	52	63
Freeboard	54	63	51	28
Floodplain	81	81	75	30
Flood stage	36	45	82	30
Level of protection	100	100	56	37
Flood fringe	54	72	26	55
Floodplain management	63	90	77	60

3) <u>General Information on Floods and Flooding</u>. This portion of the interview was intended to obtain a measure of the participants' general knowledge about floods and flood loss reduction measures. Participants were asked to choose among several answers for each of 19 questions and to then indicate their level of certainty about their answer. The participants averaged 64 [57] percent correct answers and indicated an average level of confidence of 45 [37] in their answers. Table 3 lists some of the subject matter of the questions and the respective percentage of correct answers and levels of confidence.

4) <u>Sacramento's Flood Problem</u>. This portion of the written interview was intended to obtain a measure of the participants knowledge about the flood problem in the Sacramento area. Participants were asked to choose among several answers for each of 22 questions and to then indicate their level of certainty about their answer. For an additional two questions, participants were asked to supply answers. The two questions for which multiple answers were not provided asked the participants to: a) identify any major alternatives for reducing flood losses along the American River that they were aware had been considered; and b) identify the purposes of Folsom Dam of which they were aware. Participants identified an average of 2.2 [3] alternatives for reducing flood losses with individuals mentioning from 0 [2] to 5 [5] alternatives. On the second question, participants identified an average of 3.1 [3-2] purposes with individual responses ranging from 2 [0] to 4 [5] correct responses.

Table 3
General Information on Floods and Floods and Flooding

Subject	Percent Correct (Initial)	Percent Correct (Final)	Confidence Level (Initial)	Confidence Level (Final)
Annual probability of 100-year flood	54	54	60	53
Likelihood of another flood after one occurs	100	100	67	48
Federal cost sharing for flood damage	72	90	53	30
Non-federal share of cost for dams and levees	90	81	55	44
Probability of flooding on 100-year floodplain	36	18	47	45

In the initial round of interviewing, for the 22 questions for which multiple choice answers were provided, the participants averaged 62 [59] percent correct answers with an indicated confidence level of 56 [37]. Table 4 lists some of the subject matter of these 22 questions and the respective percentage of correct answers and levels of confidence.

Table 4
Sacramento's Flood Problem

Subject	Percent Correct (Initial)	Percent Correct (Final)	Level of Confidence (Initial)	Level of Confidence (Final)
Season when floods are most likely	27	45	16	48
Size of February 1986 flood	45	27	56	20
Role of Corps of Engineers	36	27	62	43
Average annual flood losses in Sacramento	27	9	0	10
Location of Folsom Dam	100	100	51	9
Current level of protection vis a vis 1986 flood	36	36	67	37

5) Planning Procedure and Status. This portion of the interview was intended to obtain a measure of the participants' knowledge the overall procedure for the planning that was being followed in the American River Watershed Investigation and the current status of that planning. Participants were asked to choose among several answers for each of 5 questions and to then indicate their level of certainty about their answer. Participants averaged 44 [40] percent correct answers and indicated an average level of confidence of 62 [53] in their answers.

6) Views and Opinions. This portion of the interview was intended to identify participants' views on a number of policy-type issues. Participants were asked to choose among several offered answers or provide their own answer(s) for each of 7 questions. Table 5 shows the respondents views on the different sources of information available to them.

Table 5
Respondents' Perceived Credibility of Flood-Problem Information Sources
(Greatest credibility = 1; Least credibility = 7)

Source	Relative Rank (Initial)	Relative Rank (Final)
Sacramento area elected officials	4.1	4.4
Sacramento area local government professional staff	2.9	2.4
Corps of Engineers staff	2.5	1.6
State agency staff	2.8	2.4
Newspaper editorials and articles	3.3	4.8
Chamber of Commerce	3.6	5.3
Environmental organizations	5.3	5.1

General Observations on Public Information Programs. The role of the Corps of Engineers in a complex study like that conducted for the American River Watershed is one of collecting and analyzing pertinent data and information, investigating alternatives and eventually recommending whatever actions appear to deal best with the problem. The agency is not a dispassionate observer with no stake in the outcome. The opportunity to proceed from planning to design and construction is a welcome one to an engineering organization of the Corps' type. On the other hand, the Corps is not free to promote approval of a proposed project like some private special interest. The staff of the agency are bound by professionalism as well as by voluminous laws, regulations, guidance manuals and other instructions. The view of the majority of Corps personnel is doubtless that the agency is the "honest broker" presenting facts and providing technical expertise.

While the Corps may recommend an action and show it to be beneficial, the decision to proceed beyond the planning stage depends in part on approval of the proposed action or project by the elected officials and other key people in the project area. This approval need not be unanimous and it is not alone sufficient to ensure moving ahead. However, lack of a general approval almost certainly dooms a project.

Because of this need for local approval, it is customarily assumed by water resources planners that it is important for the local officials to understand the key facts about the flood problem, the alternatives investigated, and the recommended actions. Many feel that it is important also for the general public to be well informed on the proposed action and the reasons why it is recommended because of the public's influence on local officials.

Findings and Recommendations. The following sections pertain specifically to the situation in the Sacramento Case Study.

1) Selection of Study Participants. The number of study participants was limited by funding and their method of selection, as explained earlier, was informal. If there was a deficiency in the selection of participants, it was in choosing representatives of some organizations that were too far out of the local decision-making process. This was done deliberately so as to avoid any "too well educated" participants.

Participants should be chosen from those that are in the thick of the study and controversy. This will provide the best measure of the understanding of local officials and "influentials." It will also enable the process to provide some initial steps toward consensus building.

2) Number of Participants. Twenty participants (subjects) were originally identified for the study. Of the 20, only 19 completed the first round of interviews and substantial difficulty was experienced in getting the last few of those to complete their promised role. By the time of the second round of interviews, only seven of the twenty were willing to complete their promised role and another four partially completed their participation.

This is too small a number of participants to serve as surrogates for the important interests and views and range of people represented. It is also too small a sample for reliable statistical analysis. It would have been preferable to begin with about fifty participants had funding for that level of work been available. Also, the length of the written interview may have been daunting.

3) Method of Performing Interviews. In the first round of interviews, the investigator met with the participant, delivered the interview form and instructions, and waited for the subject to complete the form. This achieved a high level of properly completed forms (19 out of 20). During the second round of interviews, most participants were mailed or given the interview form and asked to complete it and mail it back within two weeks. This was somewhat unsatisfactory as evidenced by the low number (7 of 20) of properly completed forms.

It would be preferable to personally hand out the form, have the participant complete it in the investigator's presence, and collect it on the spot. This would increase participation, speed up the process, ensure sections of the interview form are not omitted, and block any possible effort by participants to copy the form, look up answers, or ask others for assistance. Also, the interview and form (questions) were too long and complicated to encourage their participation and willingness to learn more.

4) Initial Level of Understanding of Participants. The Corps study had been underway for several years at the time this investigation was initiated. The selected participants had presumably studied some of the following reports issued by the Corps.

- Special Study on the Lower American River, March 1987

- Information Paper: American River Watershed, November 1987
- Reconnaissance Report: American River Watershed Investigation, January 1988
- Initial Appraisal Report, Sacramento Urban Area, May 1988

In addition, most of the participants had been exposed in other ways to the study including attendance at meetings where the study was explained and individualized briefings. According to later interviews with Corps personnel, all difficult to understand terminology had been removed from reports that were issued. Nevertheless, for a list of terms taken largely from Corps reports, participants indicated understanding of only about half of the terms. Even this relatively poor showing is thought to be inflated by participants' overestimation of their knowledge. The interview contained no safeguard against such errors and no means of detecting such errors.

For 10 key terms that are basic to understanding flood control work, participants scored 64 percent correct but with a confidence level in their answers of only 54 [halfway between a pure guess and certain knowledge]. Again, both the percentage of correct answers and the degree of certainty are suspected to be high. There was no means of detecting guessing and it was not unusual to find participants claiming a high degree of certainty about a wrong answer.

With respect to general information about floods, participants averaged 64 percent correct answers and a degree of certainty of 54. Regarding knowledge of Sacramento's flood problems, scores were even worse. Participants averaged only 44 percent correct answers.

These low scores suggest that it would have been difficult for the participants to obtain an in-depth and correct understanding of the Corps study results through either the written reports or formal presentations. Yet, few questions were asked at informational meetings.

An extensive investigation should be made at the outset of any major study to assess the extent to which the local officials and other influential understand flood-related terminology and concepts. Audiences for reports and presentations should be specifically identified and the information on levels of understanding should be used to guide the report writing and preparation of presentations. In addition, key materials should be tested on a sample of the intended audience to ensure they are easily understandable.

In addition, emphasis should be put on conducting information exchange in an atmosphere that is conducive to asking questions and special care should be given to soliciting such questions. It should never be assumed that a lack of questions or only a few good questions means that full understanding has been achieved.

5) <u>Improvement of Scores Over Time</u>. Comparison of the participants' performance on the first and second interviews shows little improvement in their level of knowledge over the

intervening period during which they dealt with the "Alternatives Report" and the draft "Feasibility Report." For each improved score, one can point to a score that showed less knowledge. The variations in any event tend to be small and well within the accuracy of analysis using such a small sample. This failure to improve over the time and number of informational opportunities that were available suggests that the public information program was not effective. That this fact went undiscovered by the Corps personnel points out the need for operating some type of feedback mechanism over the course of the study.

Public informational programs should be designed based on identification of each intended audience, analysis of each audiences' beginning level of understanding, and a clearly stated goal as to the improvements in understanding to be sought for each audience.

Following design of the public information program, a continuing program of testing and information collection should be implemented to measure progress toward the goal for each group and to guide staff in putting emphasis on critical issues.

6) <u>The Corps as "Honest Broker</u>." The Corps was ranked as the most credible source of information about the flood problem at Sacramento. However, that top ranking was not the result of unanimous agreement as to the agency's credibility. Indeed, the Corps was ranked most credible by only a minority of the participants. The high ranking was a result of being consistently ranked in the upper part of the spectrum and never lower than fourth.

With regard to the best solution to Sacramento's flood problem, individuals ranked the Corps credibility from first to sixth. In fact, it was rated the most credible by only three of the 11 participants whose views were tallied. The agency's top rating, tied with local government professional staff, was again due to being often in the top part of the rankings rather than any clear consensus on the Corps' impartiality.

Corps personnel do not see their agency as others see it. The Corps' performance and assumptions about important matters are likely to be affected by the overly optimistic view of the District personnel about how the agency is perceived by the public. This kind of error in understanding the framework in which planning and information exchange takes place can breed attitudes which can be seen as arrogance by local officials and which can further interfere with effective communication.

The Corps faces a credibility problem with several audiences. Dealing with this problem requires that the agency's personnel recognize that others have ideas that they believe are important. Less emphasis should be put on the Corps overwhelming command of physical and technical facts and more time on consensus building. This will require providing mechanisms to identify and recognize the beliefs and ideas of others and letting others share in the true decision-making.

Letting others share in the decision-making will not be an easy task. Especially in the

case of groups lacking technical capability, it may be necessary for the Corps to provide the group with the funding or other assistance needed to participate in a meaningful way.

7) Need for Staff Education. Few if any of the Corps project managers and planners have a background in risk communication. They are likely to be unaware of the requirements for good communication and effective participation. They may also be unsympathetic to the need for improved public information. A need exists for educating them.

A two-pronged effort should be mounted to sensitize key planning staff about the needs for and means of effective communication. One part of the effort should focus on gaining some familiarity with the literature in the field of risk communication. The second should be the provision of good models of how effective public information programs can be designed and carried out. There is no substitute for demonstrated success.

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Overview of the Flood Damage Analysis Program (HEC-FDA)

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Abstract

The Hydrologic Engineering Center (HEC) has developed a next generation Flood Damage Analysis computer program (HEC-FDA) for formulating and evaluating flood damage reduction plans. The program streamlines the study process following functional elements of a study involving coordinated study layout, hydrologic engineering analysis, economic analysis, and plan formulation and evaluation. The program has the capability to quantify uncertainty in discharge-frequency, stage-discharge, geotechnical levee failure, stage-damage functions, and incorporate these uncertainties into economic and performance analyses of alternative flood damage reduction plans. Plans are evaluated by expected annual damage associated with a given analysis year or the equivalent annual damage over the project life of the plan. Information on the flood risk performance is also included in the results. Output includes tables and selected graphics of information by plan, analysis year, stream, and damage reach for the plan. Results of the various plans may also be compared. The program design is consistent with federal and Corps of Engineers policy and technical requirements. The program operates on Windows NT and 95, and Unix-based computer operating systems.

Introduction

The Corps of Engineers requires use of risk-based analysis procedures for formulating and evaluating flood damage reduction measures (USACE, 1996). Procedures developed are now applied to ongoing Corps studies. They quantify uncertainty in discharge-frequency, stage-discharge, stage-damage functions and incorporate it into economic and performance analyses of alternatives. The process applies Monte Carlo simulation (Benjamin et al., 1970.), a numerical-analysis procedure

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Hydrologic Engineering

General. Hydrologic engineering analyses are required for defining hydrologic engineering relationships for the specific study setting. Required hydrologic engineering data for plan evaluation are typically water surface profiles, discharge- or stage-probability functions with uncertainty, stage-discharge (rating) functions with uncertainty, and data describing levees, including data that describe flooding characteristics associated with them. These data are developed for each plan, analysis year, stream, and damage reach that have been defined as part of the study configuration. The data is defined in the HEC-FDA program by selecting hydrologic engineering (**HydEng**) from the main program window and are described in the order that the elements appear on the menu. See Figure 4.

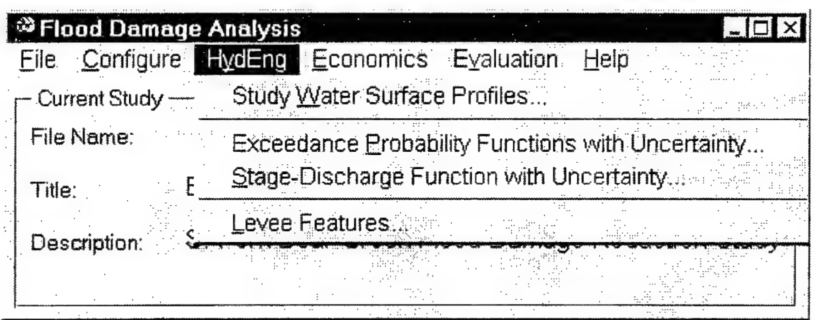
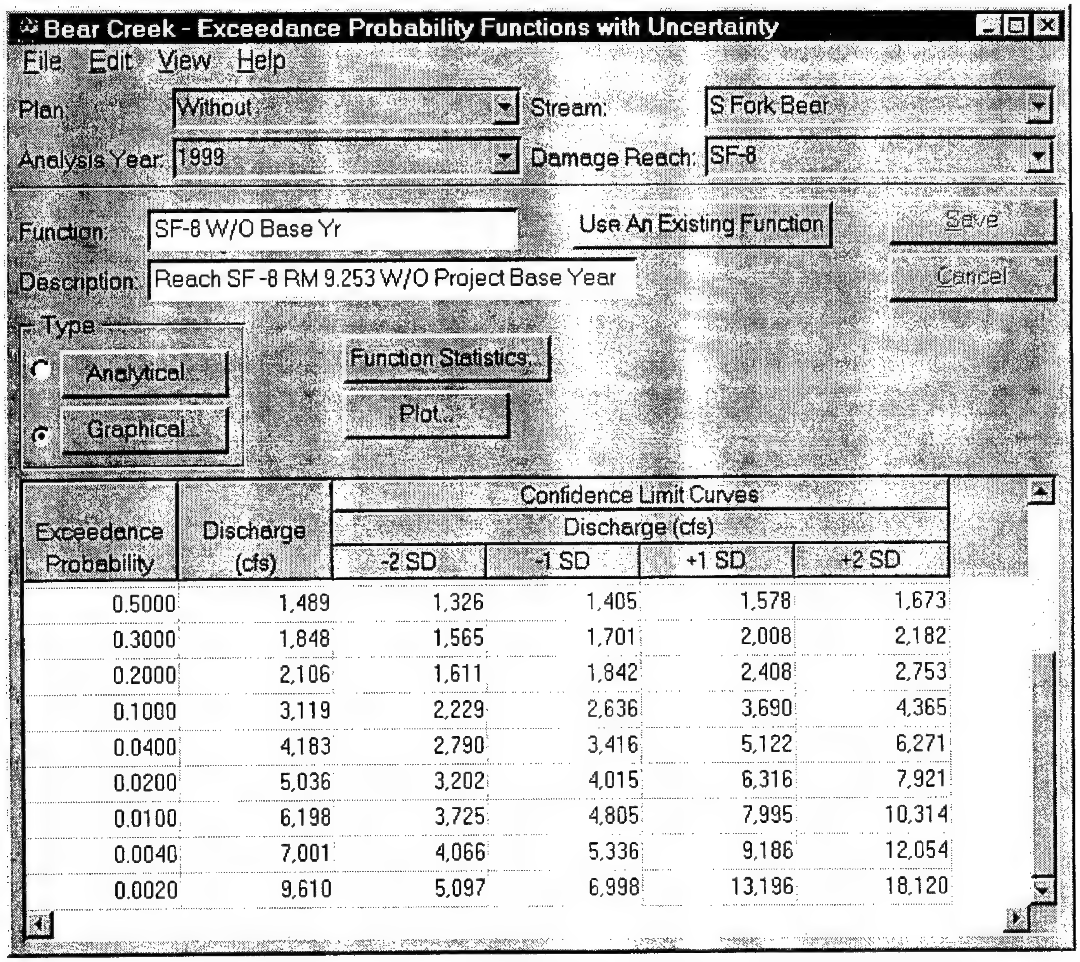


Figure 4. Hydrologic Engineering Elements

Water Surface Profiles. Water surface profiles are required to aggregate stage-damage-uncertainty functions at damage reach index locations. They are also used in development of the stage-discharge functions. The profile data are normally imported from stream hydraulics programs such as the HEC River Analysis System package (HEC-RAS). The data may also be entered manually. The HEC-FDA program requires specific water surface profiles for the 50-, 20-, 10-, 4-, 2-, 1-, .50-, and .20- percent chance exceedance frequency flood events.

Exceedance-Probability Functions. The derivation of exceedance-probability functions is dependant on data availability. For gaged locations and where analytical methods are applicable, the HEC-FDA program uses procedures defined by the Interagency Advisory Committee on Water Data (1982). Uncertainties for discrete probabilities are computed using the non-central *T* distribution. For ungaged locations, the cumulative discharge-frequency is adopted from applying a variety of approaches (Water Resources Council, 1981). The adopted function statistics are then computed similar to gaged locations. The equivalent record length is specified based on the perceived reliability of the information. Regulated discharge-frequency, stage-frequency, and other non-analytical or graphical frequency functions require different

methods. An approach referred to as order statistics (Morgan et al., 1990) is used to compute the cumulative frequency and uncertainty relationships for these situations. Figure 5 shows an example frequency screen of HEC-FDA with tabulated results and Figure 6 shows a plot of the frequency function with uncertainty.



Exceedance Probability	Discharge (cfs)	Confidence Limit Curves Discharge (cfs) -2 SD	-1 SD	+1 SD	+2 SD
0.5000	1,489	1,326	1,405	1,578	1,673
0.3000	1,848	1,565	1,701	2,008	2,182
0.2000	2,106	1,611	1,842	2,408	2,753
0.1000	3,119	2,229	2,636	3,690	4,365
0.0400	4,183	2,790	3,416	5,122	6,271
0.0200	5,036	3,202	4,015	6,316	7,921
0.0100	6,198	3,725	4,805	7,995	10,314
0.0040	7,001	4,066	5,336	9,186	12,054
0.0020	9,610	5,097	6,998	13,196	18,120

Figure 5. Graphical Exceedance-Probability Function with Uncertainty

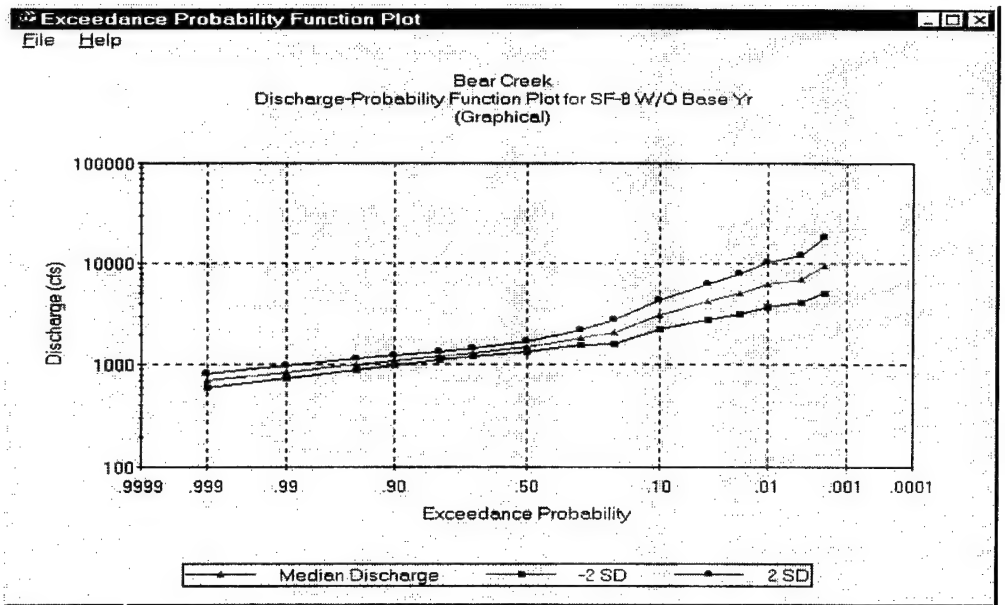


Figure 6. Plot of Exceedance-Probability Function

*Stage-discharge Functions. Stage-discharge or rating functions are defined by observed data or computed water surface profiles. The relationships and uncertainty are entered directly into HEC-FDA for both types. Probability density functions of errors may be normal, log normal, triangular, or uniform. For observations, uncertainty is calculated from deviates of the best fit cumulative rating function. Computed profiles are required for ungaged locations and modified conditions. For these, the corresponding water surface profile data set provides eight discharge-stage ordinate values plus the invert for zero discharge as initial definition of the rating at the damage reach index station locations. Additional points may be added to define the function. Figure 7 shows a plot of the rating with uncertainty.

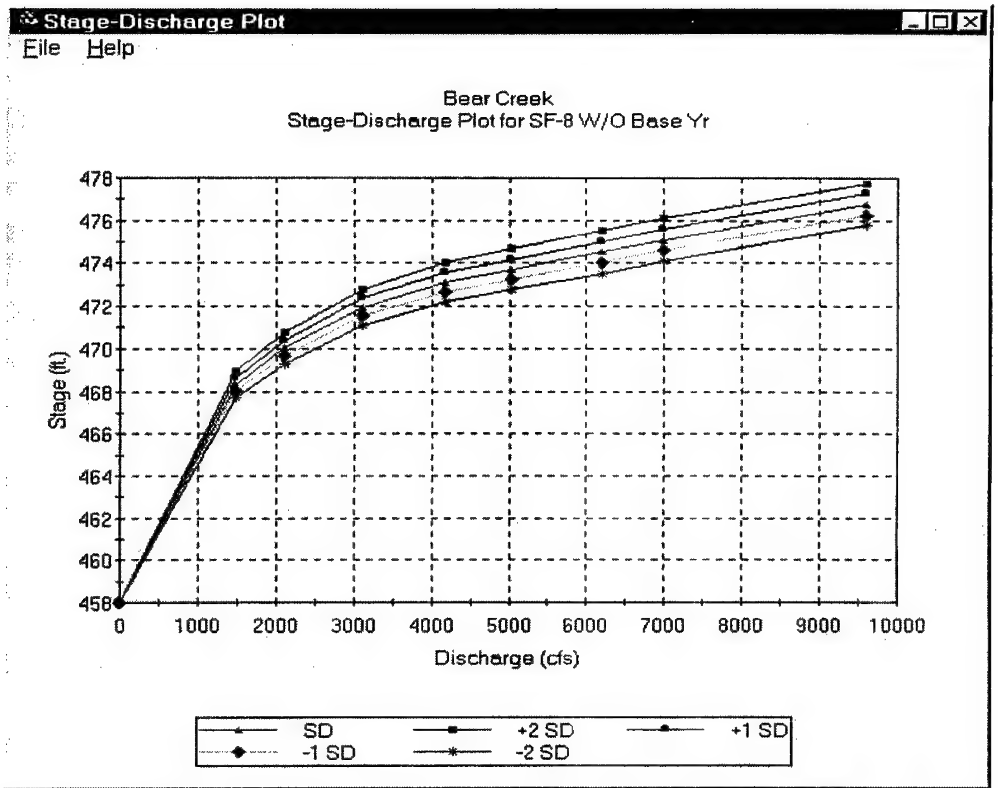


Figure 7. Stage-Discharge Plot

Levee Features. Under Levee Features, the user specifies levee size and failure characteristics, interior versus exterior stage relationships associated with the levee, or wave overtopping criteria. The levee, floodwall, or tidal barrier characteristics are entered and other relationships are defined depending on whether the levee is subject to geotechnical failure or wave action (overtopping) which may cause flooding. A levee or floodwall is defined by selecting the appropriate Plan, Year, Stream, and Reach in the Levee Feature window. The elevation of the levee or floodwall is entered in the appropriate field (Figure 8).

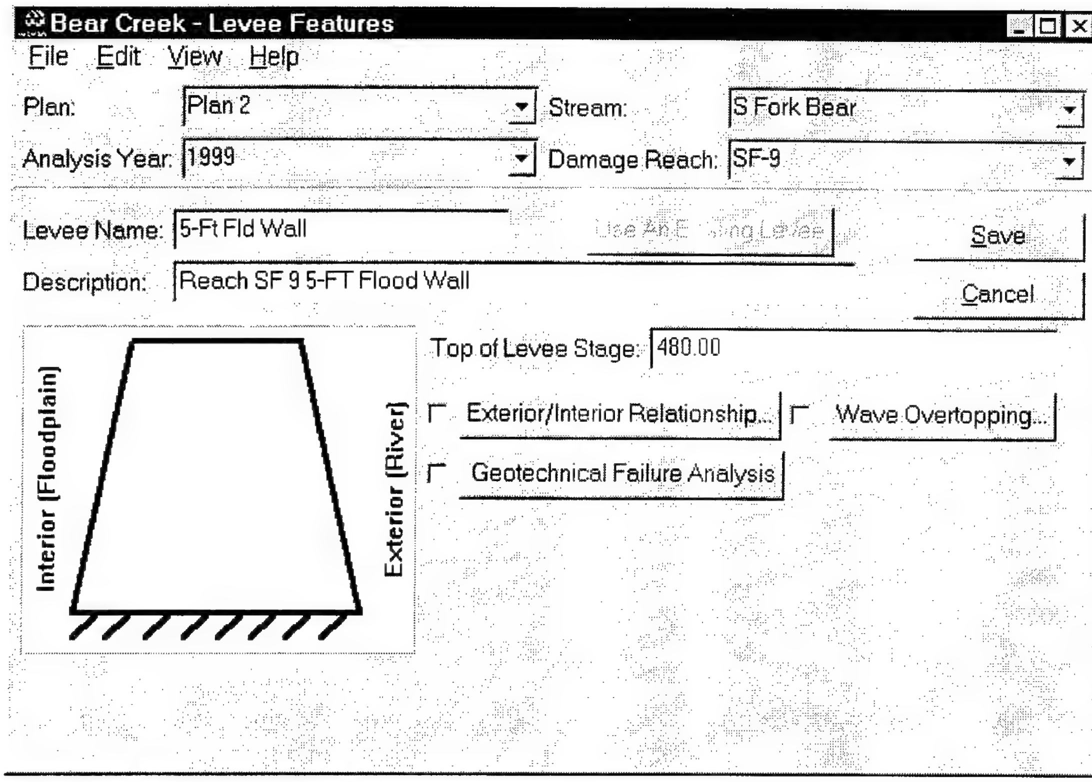


Figure 8. Levee Features

As can be seen on the Levee Features window (Figure 8), other data that describe the characteristics of levees and floodwalls and how they affect flooding can be specified. These features are briefly described. Detailed descriptions of these features are included in the program User's Manual.

(1) *Exterior-Interior Relationship* - The purpose of this feature is to define a relationship between the stage on the river or exterior side of the levee vs. the stage in the flood plain or interior side of the levee. This relationship is necessary if water that overtops the levee from the river side will not reach the same level as the top of the levee in the flood plain. This may be due to floods that result in stages near the top of the levee overtopping in a safe, controlled manner, as designed or flood hydrograph volume is not sufficient to fill the flood plain to the stage equal to the top of the levee. In either case, the relationship must be developed from hydrologic or hydraulic analyses external to the HEC-FDA program. If the relationship is not specified, the assumption is that the flood plain fills to the stage in the river (represented by the rating curve for the reach) for all events that result in stages that cause levee failure or are above the top-of-levee.

(2) *Geotechnical Failure Analysis.* A relationship between water elevation on the river or exterior side of the levee vs. the probability of levee failure may be specified,

if appropriate. This may be necessary for existing non-federal levees or older levees that may have deteriorated and can no longer be assumed to hold water to the stage initially intended. The relationships are developed from geotechnical analysis according to existing geotechnical guidance.

(3) *Wave Overtopping*. Wave Overtopping Analysis allows the user to account for effects of wave overtopping when analyzing levees, floodwalls or tidal barriers. A wave height versus still water stage relationship is specified. Still water stage corresponds to the exterior stage-discharge or stage-frequency function specified for the reach. The uncertainty of wave height is defined by specifying one of several error distribution types. When a levee or floodwall is subjected to wave action, a portion of the wave may overtop depending on whether the wave strikes the structure. The volume of water that spills over the levee or floodwall is dependent on the effective overtopping height. Wave overtopping relationships may be used to account for these factors. A relationship between effective overtopping height and resulting interior stages can also be specified. These relationships are developed outside the HEC-FDA program using wave overtopping analyses and overtopping volume versus interior stage characteristics.

Economics

<u>General</u>. Economic analysis aggregates stage-damage-uncertainty functions by damage category, damage reach, stream, plan and analysis year using the structure inventory data and water surface profiles. These functions are used in the plan evaluation. Figure 9 shows the information the is defined under Economics.

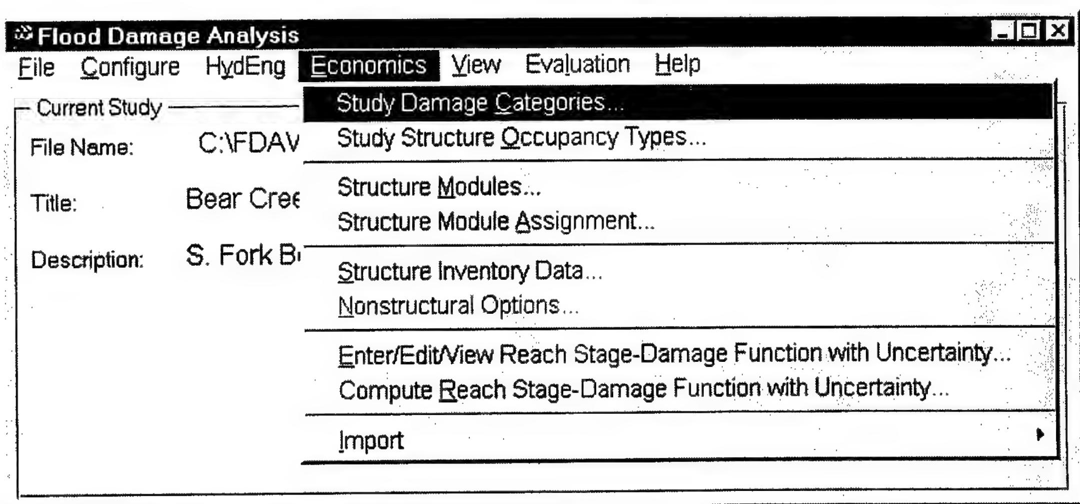


Figure 9. Defining Economic Data

<u>Damage Categories</u>. Damage categories are used to consolidate large number of structures into specific groups of similar characteristics for analysis and reporting.

<u>Depth-Damage Functions</u>. Depth-damage functions define the percent of the structure damage for a range of flood stages at a structure. The percent-damage is multiplied by the structure value to get a unique depth-damage function at the structure. The zero depth is assumed to coincide with the stage (elevation) of the first floor. The depth-percent damage functions are input directly or imported from external files.

<u>Structure Inventories</u>. Inventories of floodplain structures are performed to develop structure attribute information on unique or groups of structures relevant to flood damage analysis. The information is entered and stored in HEC-FDA for subsequent calculations to produce stage-damage-uncertainty information at the damage reach index locations. Structure attributes include the following: location addresses, stream station and/or coordinates; reference stages; damage category and depth-percent damage function assignments; structure and content values, and uncertainty parameters. Data can be entered in a table or "spreadsheet" type form, if desired. The data may also be imported from external files. An illustration of some of the information included in structural inventory is included on Figure 10.

Bear Creek - Structure Inventory

File Edit View Utilities Help

	Stream Station	Structure Value ($1,000's)	Content Value ($1,000's)	First Floor Stage (ft)	Damage Category Name	Structure Occupancy Type	Structure Module Name	Stream Name	Bank	Damage Reach Name
399	9.900	73700.00	36850.00	476.99	COMM	30S_30C_	Base	S Fork Bear	left	SF-8
402	9.750	241.50	120.75	476.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
403	9.730	237.40	118.70	476.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
404	9.710	344.40	172.20	477.00	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
405	9.690	232.30	116.15	476.75	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
406	9.660	232.30	116.15	476.81	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
407	9.640	344.40	172.20	475.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
408	9.620	232.30	116.15	475.63	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
409	9.600	294.50	147.25	475.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
410	9.580	232.30	116.15	476.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
411	9.565	237.40	118.70	476.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
412	9.500	240.50	120.25	476.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
413	9.475	355.60	177.80	474.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
414	9.450	281.20	140.60	472.00	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
415	9.420	303.70	151.85	472.25	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
416	9.380	470.80	235.40	472.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8

Figure 10. Structural Inventory Data Table

Stage-damage Functions. Stage-damage-uncertainty functions are required for each damage category, damage-reach, plan and analysis year. They may be entered directly or computed and aggregated to the index location based on the structure inventory attributes and specifications and associated water surface profiles. A plot of the stage-damage function with uncertainty is shown on Figure 11.

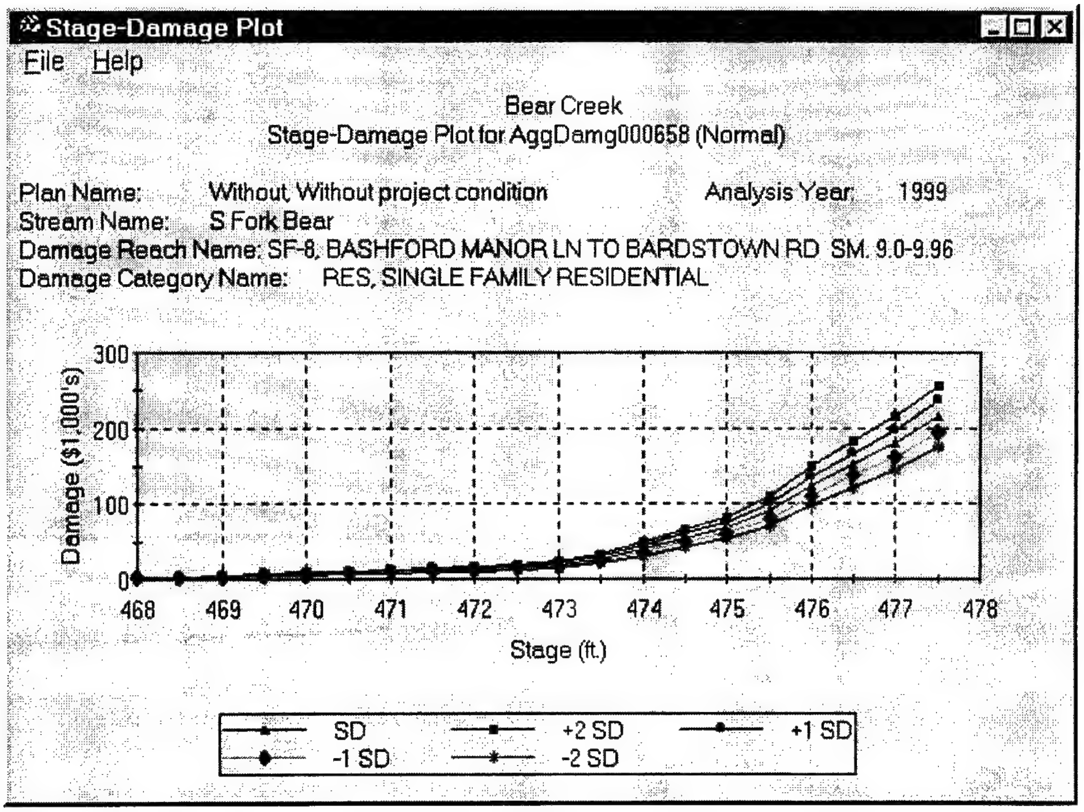


Figure 11. Stage Damage Function with Uncertainty

Evaluation

Evaluation is where HEC-FDA performs computations for specified plans and output results are available for viewing. The analyses are performed using Monte Carlo simulation to numerically integrate the large number of possible combinations of damage-frequency functions associated with defined uncertainties in the frequency, stage and damage functions. Figure 12 shows study evaluation options. Under evaluation you specify the type of analysis to be performed. The choices are to view a study status report (Figure 13), conduct analysis by plans for a specific analysis year, conduct analysis of equivalent annual damage, or view study results, if analyses have been completed.

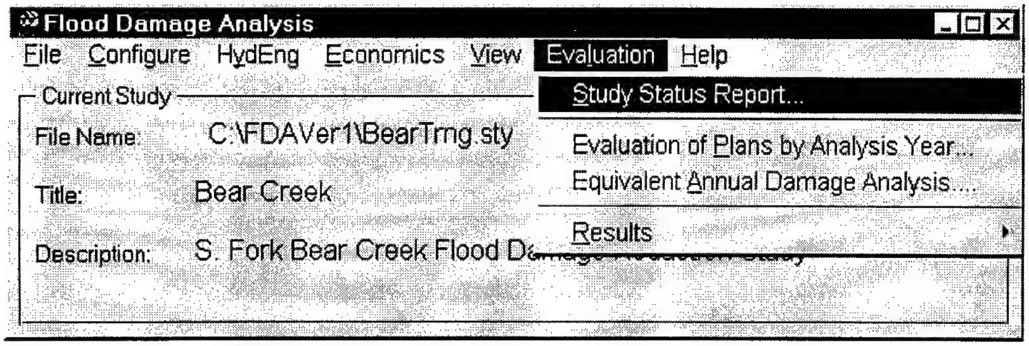


Figure 12. Study Evaluation Options

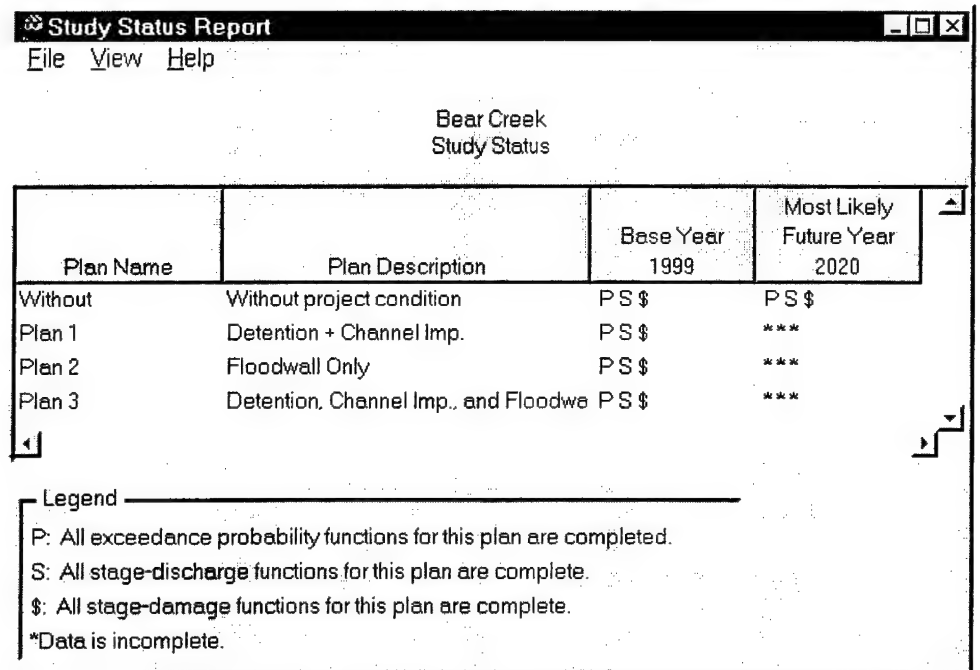


Figure 13. Study Status Report

Results

Information on the flood risk performance and expected annual damage is included in the results. Output includes tables and selected graphics of information by plan, analysis year, stream, and damage reach for the entire plan. Plan comparisons may also be performed. The choices under Results are displaying reports of (1) expected annual damage by analysis year, (2) equivalent annual damage, or (3) project performance. Figure 14 shows these options.

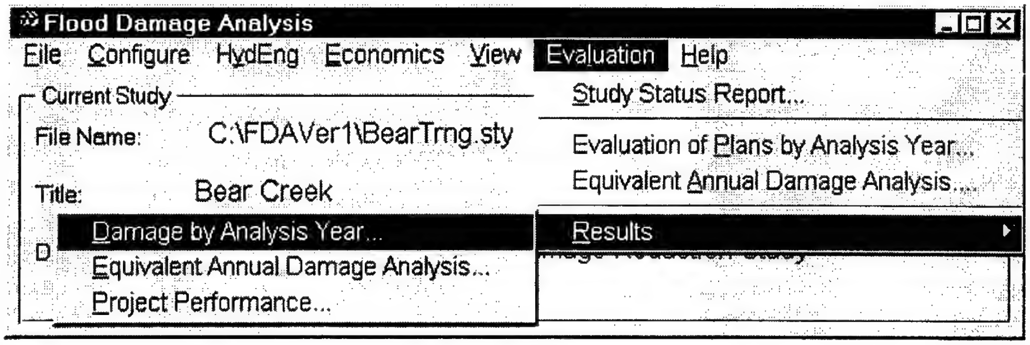


Figure 14. Study Analysis Results options

Expected Annual Damage by Analysis Year. When this option is selected, the window shown on Figure 15 appears and the analyst can select the desired combination of analysis results he or she wants in the report. An example output report for an analysis of several alternative levee plans for a damage reach is shown in Table 1.

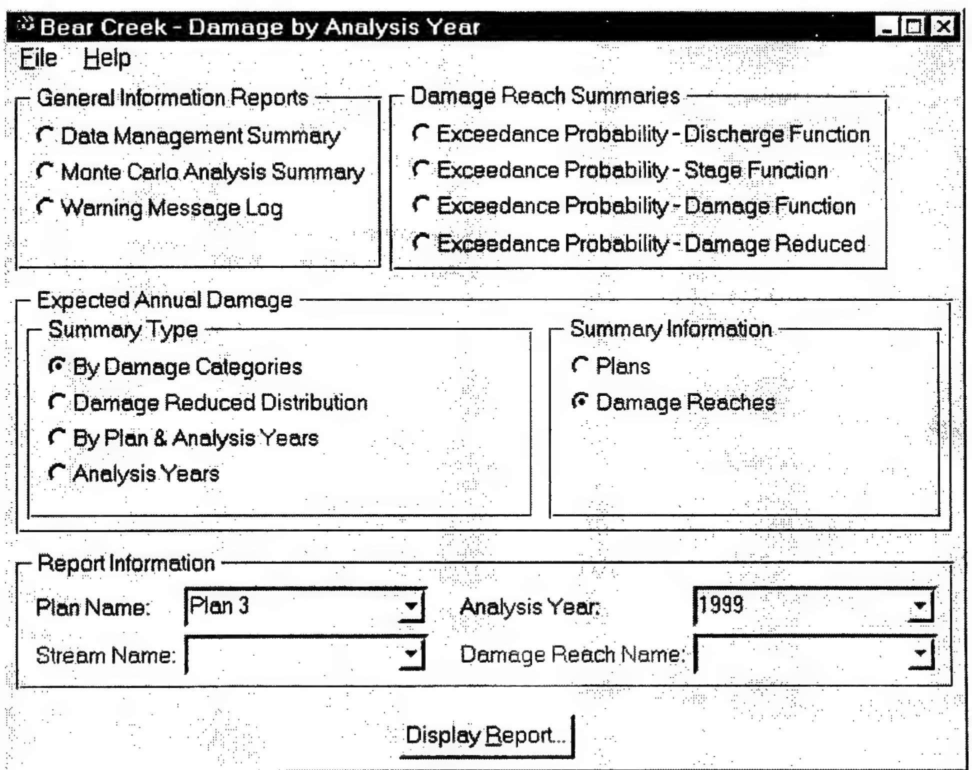


Figure 15. Damage by Analysis Years report Options

Table 1
Expected Annual Damage by Plan

Plan Name	Plan Description	Expected Annual Damage ($1000)		
		Without Project	With Project	Damage Reduced
Without	Without Project	78.3	--	--
Plan 1	16.5' Levee	78.3	72.9	5.4
Plan 2	19.1' Levee	78.3	63.1	15.2
Plan 3	21.9' Levee	78.3	49.1	29.2
Plan 4	23.0' Levee	78.3	43.1	35.2
Plan 5	24.0' Levee	78.3	30.2	48.1
Plan 6	25.5' Levee	78.3	26.6	51.7
Plan 7	26.0' Levee	78.3	23.1	55.2
Plan 8	27.0' Levee	78.3	17.4	60.9

Project Performance. Project or plan performance is a measure of the hydrologic efficiency of a flood damage reduction plan. Performance is measured in terms of risk of flooding in any year, over a specified number of years, or if a specific hypothetical or historical event occurs. Risk-based analysis is used to determine plan performance. The options for performance results reports are illustrated on Figure 16. Performance is based on exceedance or non-exceedance of a target stage which can be specified by the analyst based on residual flood damage for a specific event. Performance results can be displayed based on reaches for a single plan or for all plans and reaches. An example of some of output for plan performance associated with the various levee sizes is shown in Table 2.

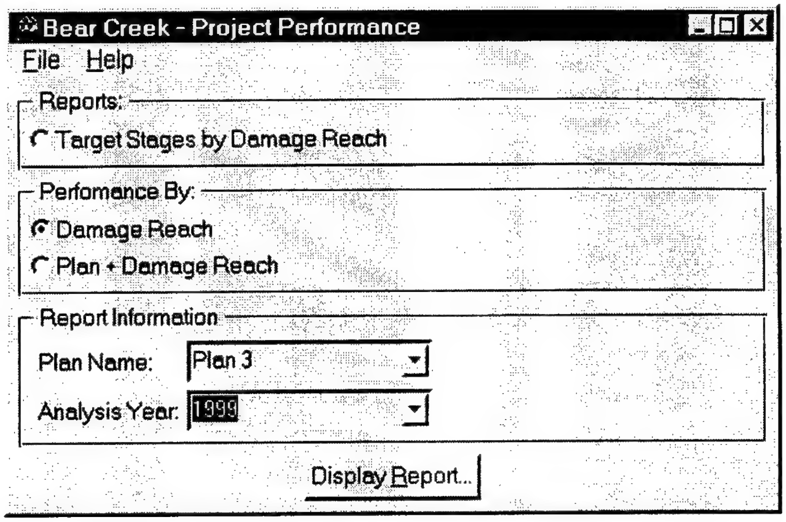


Figure 16. Project Performance Report Options

Table 2
Plan Performance

Plan Name	Plan Description	Target Stage	Expected Annual Stage Exceedance Probability	Long-term Risk in Percent for Indicated Years			Conditional Annual Percent Chance Non-Exceedance for Indicated Events		
				10	25	50	4%	1%	.2%
Without	Without Project	15.1	0.059	46.0	78.5	95.4	16.9	0.0	0.0
Plan 1	16.5' Levee	16.5	0.043	35.5	66.6	88.9	49.1	0.3	0.0
Plan 2	19.1' Levee	19.1	0.023	20.5	43.6	68.2	92.7	9.5	0.0
Plan 3	21.9' Levee	21.9	0.012	11.4	26.2	45.5	99.5	48.8	0.5
Plan 4	23.0' Levee	23.0	0.010	9.2	21.4	38.2	99.8	64.4	1.6
Plan 5	24.0' Levee	24.0	0.008	5.6	13.5	25.1	100.0	87.0	12.9
Plan 6	25.5' Levee	25.5	0.005	4.8	11.6	21.9	100.0	91.1	19.0
Plan 7	26.0' Levee	26.0	0.0045	4.1	9.9	18.7	100.0	94.1	26.8
Plan 8	27.0' Levee	27.0	0.0029	2.8	6.9	13.3	100.0	97.7	45.6

Conclusions

The HEC-FDA program provides comprehensive state-of-the-art analysis capabilities for formulating and evaluating flood damage reduction that includes risk-based analysis procedures. The program has a modern user interface and operates on multiple platforms. Computational procedures and output reports are consistent with Federal and Corps of Engineers policy and technical element regulations. Version 1.0 release is scheduled for early December 1997. The release will include a user's manual.

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UNDERSTANDING RISK AND UNCERTAINTY

(A Non-Technical Perspective)
by

Jaime Merino[1]

FIRST EXPOSURE

How we started. In the South Pacific Division, we were first exposed to the concept of "Risk and Uncertainty", **R&U** for short, at a large **I**n **P**rogress **R**eview (**IPR**) meeting for the American River Study. The Assistant Secretary's Office, as well as our Headquarters, the Division, the District, and representatives from the Local Sponsor were present. At this meeting we were told that **all** projects would require an R & U analysis. Almost no one in the meeting had a clue what R & U was all about. Over protestations by some of us, and with the assurance from our Headquarters that it would only take two weeks to conduct an R & U analysis, we were on our way.

What is R&U? Shortly after the meeting broke up, most of the senior managers wanted to know what R & U was and what we were in for. How bad could it be? We were told it would only take a couple of weeks. After several attempts at explaining to my supervisor, the Director of Engineering, what I understood the R & U process to be, he asked for a "short paper" that explained R&U for the uninitiated. The big surprise was to have that paper faxed to us from Headquarters H&H as a paper that explained R&U.

Problems. After several schedule delays because of problems getting the R&U process going for the American River Study, it was apparent to all that this was not going to be an easy task. (See below and also the Paper on the "American River Study" by Mike Deering, HEC.)

UNDERSTANDING R&U

Communication. We knew that we were going to have a considerable task explaining the results to our local sponsors when we were having problems getting our own planners and engineers to understand what we were reporting. "There is a *.x* chance of passing a *.y* flood with the project" A what? This was the first reaction, usually with glazed eyes and a blank stare. Explaining this to our local sponsors has turned out to be even more difficult.

Where we stand. At this time most of the engineers in the Hydraulics and Hydrology sections have an understanding of what R&U is all about, though there is an occasional instance where someone is just "plugging" in the numbers. Some of the staff in our Economics Sections have also acquired a good understanding of the process. If the Senior Staff does not completely understand, they have, for the most part, stopped asking questions. Our Local Sponsors..., well, that

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1. Chief, Water and Geotechnical Branch, South Pacific Division, U.S. Army Corps of Engineers

is another story. The usual question after they give up trying to understand the principles behind R&U is "Does the project get us out of the FEMA 100yr floodplain?

Because of the controversial nature of the American River Study, (Auburn Dam and the potential change to the American River Canyon), Congress directed that the Academy of Engineering of the National Research Council review the work of the American River Study. They easily understood the process, but had some difficulty understanding some of the "practical" limitations of the early versions of the software and problems that we were encountering reaching consensus on the many assumptions required for the analysis.

TECHNICAL PROBLEMS

Code. The first problems surfaced trying to use "stage-frequency" curves, rather than the more common "discharge-frequency" curves. We also had problems with the original program that we used for the Monte Carlo simulation, both problems overcome by HEC. We now have a very robust program that should handle all our applications.

Procedure. The original "program" was developed for a simple levee project. We have had to deal with complex regulated basins that were not envisioned as part of the original program such as in the American River Study. See Figures 1 and 2. Folsom Dam controls the American River to the design discharge just short of the 1 % event; that fact, together with the by-pass system makes it a very complex basin to study. As has been previously described, this was not an easy study.

"Sediment" has also been a problem in some of our studies, especially in alluvial plains, see Figure 3. In this case, the geo-morphology of the fan makes it very difficult to determine in future large events after the channel has silted up what pathway the "flood" will take. The problem here is the larger than normal number of variables, as well as the larger uncertainty of their values. The problem on this study is related to the sediment; but then again, sediment is always a problem, and would have been a problem under the "old" procedures.

We have a project that has been underway for some time, Merced County Streams, that should be a real challenge to complete, if we do R&U on that project. The project consists of 6 detention basins on tributary streams, some uncontrolled streams, channels, irrigation canals, a distributary system, all in a very flat floodplain that has few gages, and the gages that exist are by-passed in a co-mingled flood plain. See Figures 4 and 5. We presently have an exemption for this project from Headquarters.

Also, some of our "records" are so short, that the "uncertainty" is causing some of our projects to require large levees, giving us some problems. The point of all of this is to illustrate that experienced individuals are, more now than before, essential to the studies.

FEMA CERTIFICATION

History. When we first ran a "shot-gun" R&U on the American River Study, we were just short, or right at, our jointly (COE & FEMA) agreed upon criteria, (50 % reliability), for us certifying that the existing levee system would pass the "Base Flood". This was a bit of a "shock" after working on the study and knowing how close we had come to losing the levee system during the flood of February, 1986, a flood slightly smaller than the presently estimated "base flood" . This development caused considerable discussion in the H&H community as to the criteria; i.e., 50% chance of passing the Base Flood. This was causing problems to the study team, especially deciding how to present the concept of "reliability" in the report. In this particular study, with a highly controlled basin up to about the "100yr" frequency, there is no margin of safety beyond the frequency at which the discharge can no longer be controlled. We have several projects in our Division that are "certified" by us to FEMA as passing the Base Flood using this criteria, though none as critical as this one.

Present Criteria. The present criteria (90% or 95% confidence limit) will certainly give "safer" results. See Figure 6. The potential problems that this criteria may cause are surely to get us into the political arena. It is going to be very difficult to explain to our sponsors that we will be unable to "certify" some of our projects unless some additional levee height is added in order to achieve the desired "confidence" limit. There will probably be instances where our present criteria will require a higher levee than the existing FEMA criteria requires. This will probably lead to "criteria shopping" on the part of our sponsor's. This will surely also cause a problem for both the Corps and FEMA and may lead to more confusion than exists even now.

I would propose criteria that allows us to "certify" a levee if it meets the existing FEMA (3 foot of freeboard) criteria also, with perhaps a minimum 50% reliability.

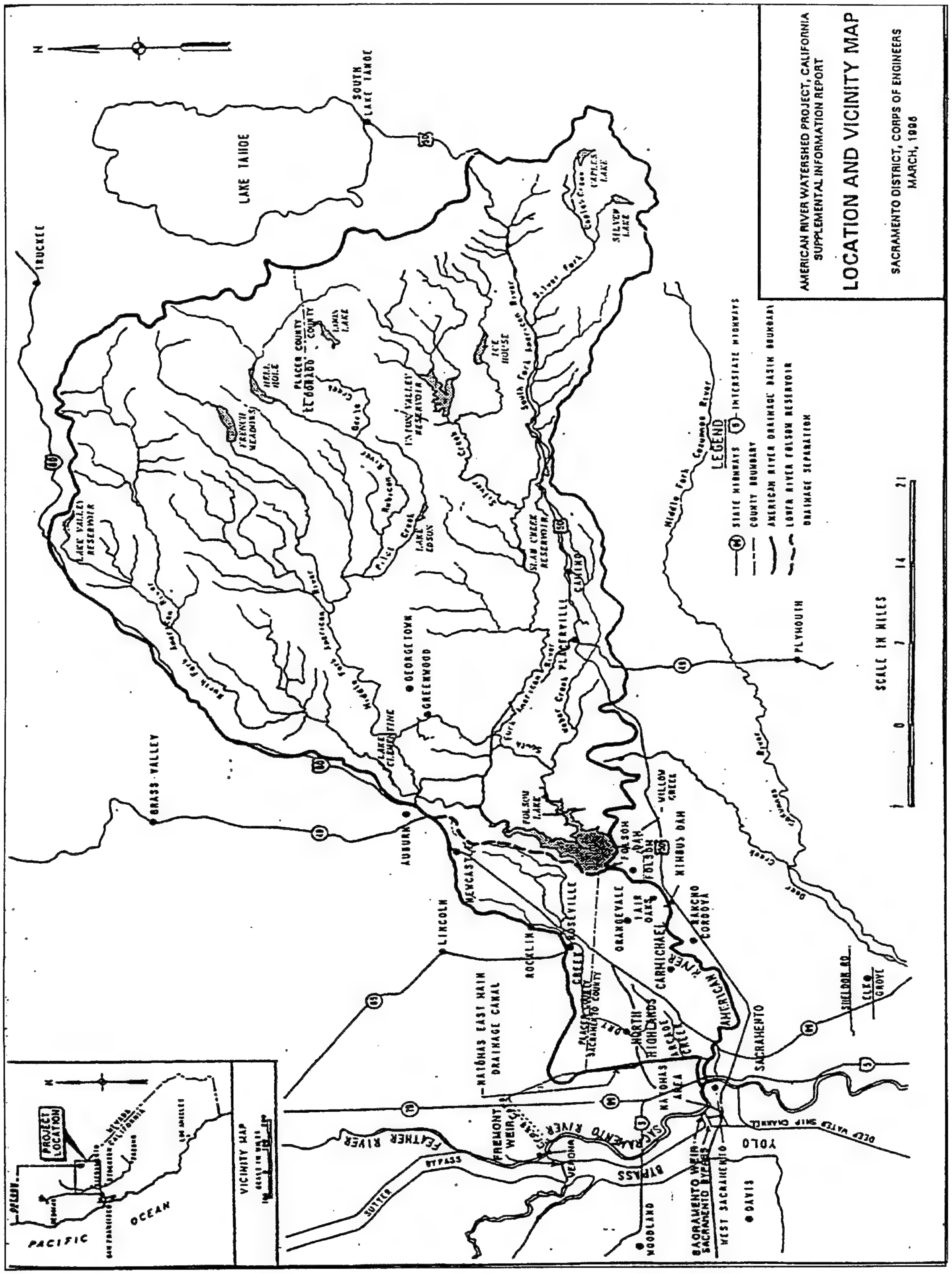


Figure 1 American River

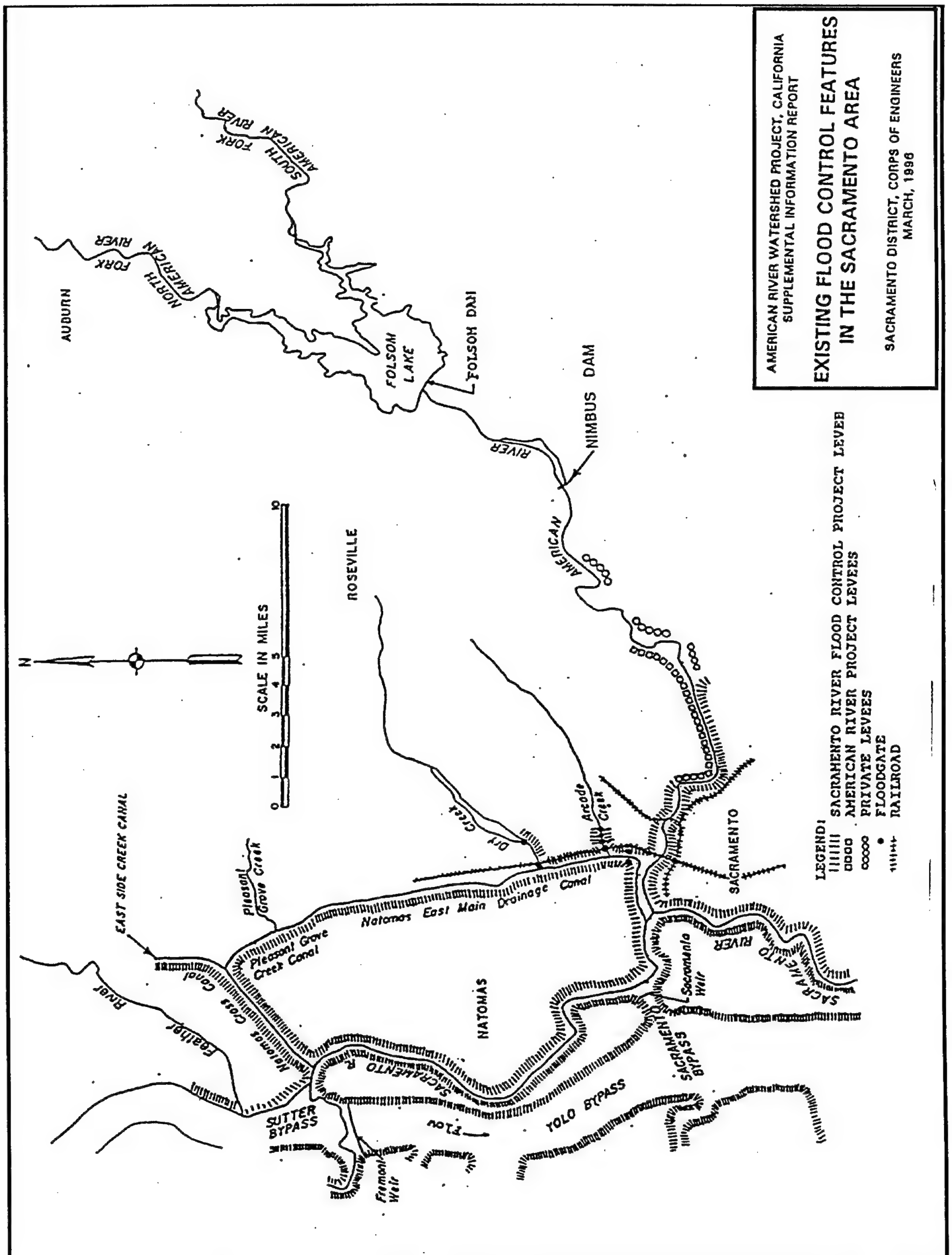


Figure 2 American River

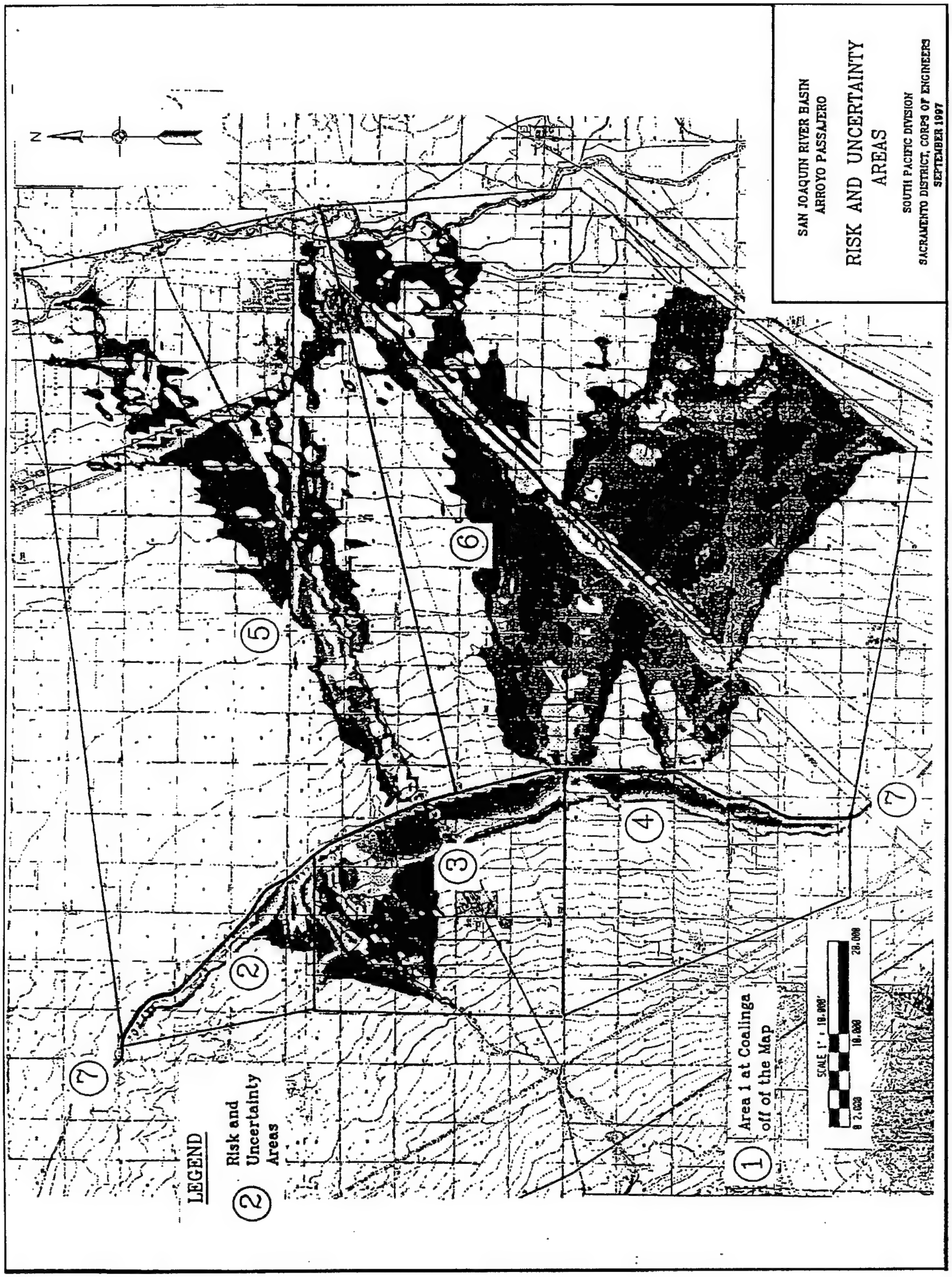


Figure 3 Arroyo Pasajero

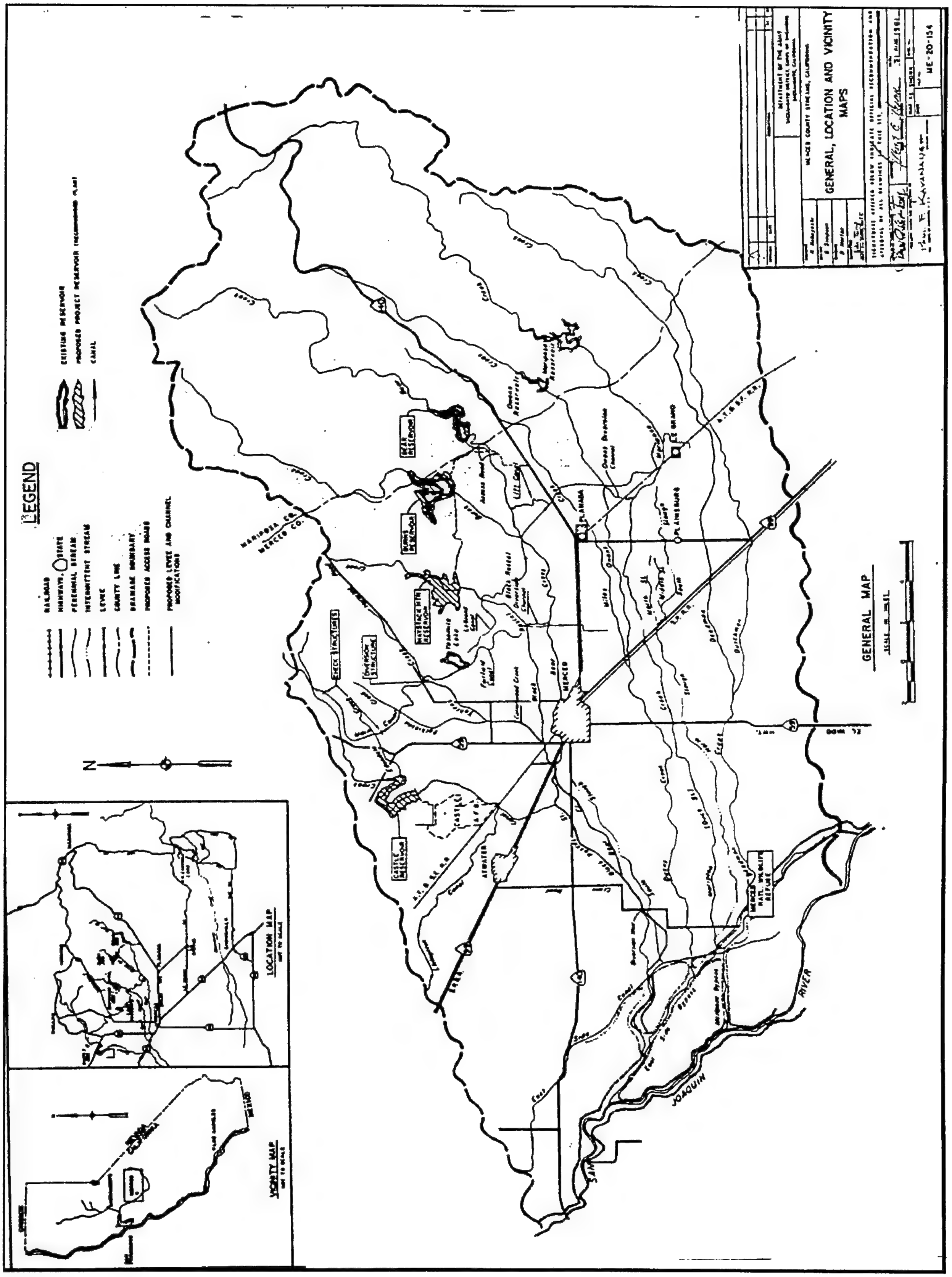


Figure 4 Merced County Streams

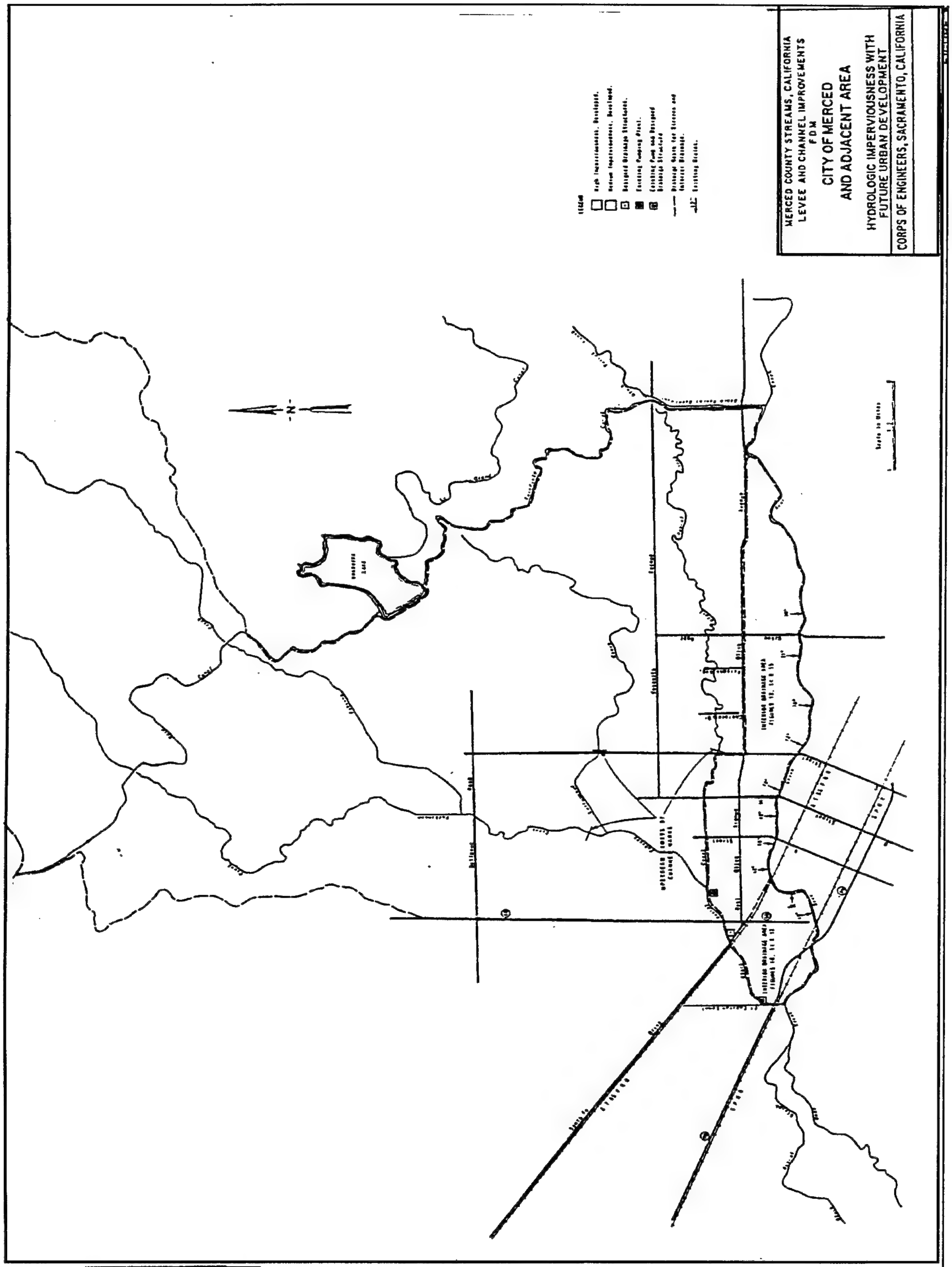
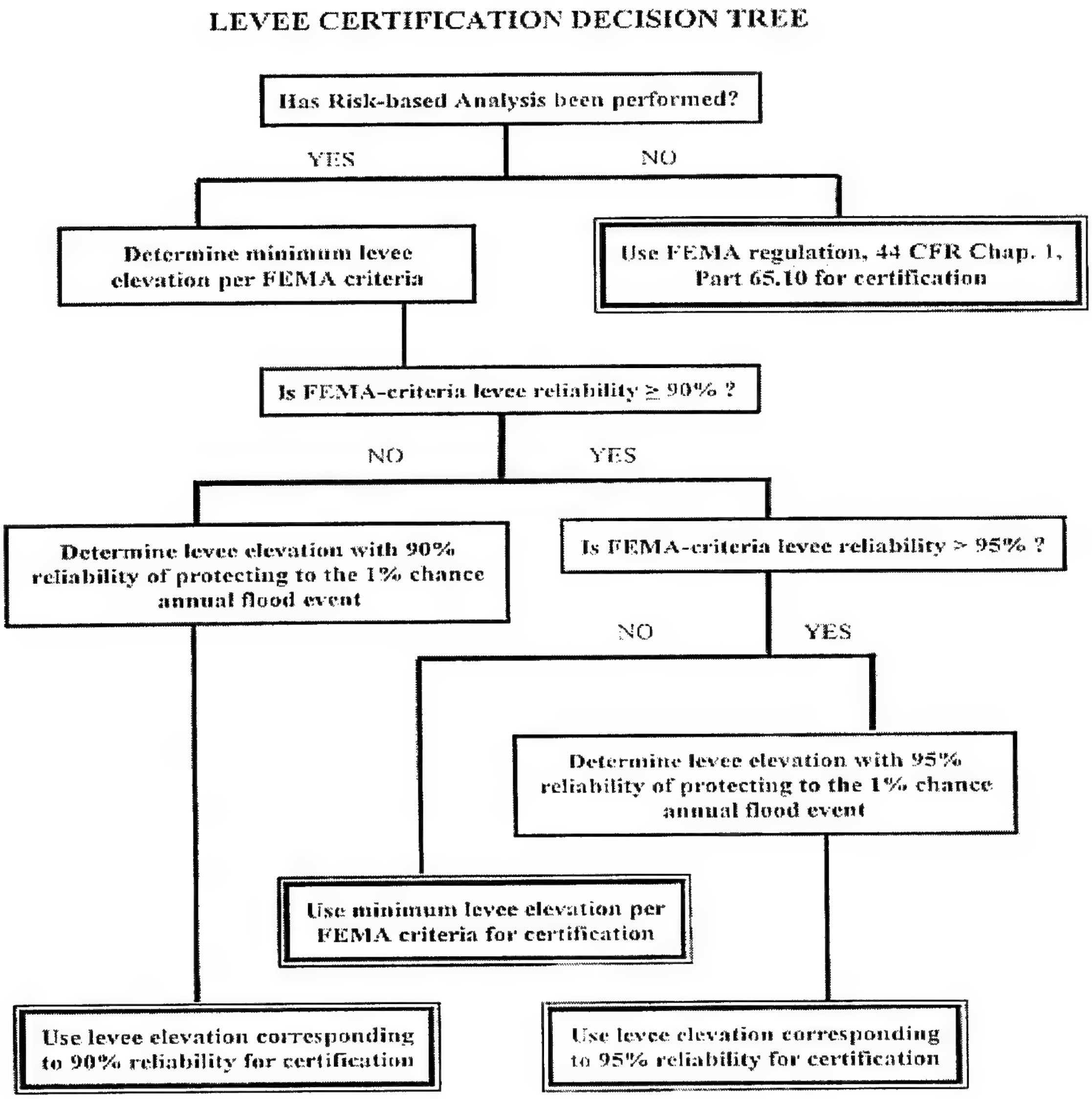


Figure 5 Merced County Streams



FEMA Criteria = 1% chance median annual flood event plus three feet of freeboard
RELIABILITY = % chance non-exceedance given the 1% chance annual event occurs

Figure 6 Levee Certification Decision Tree

OVERVIEW ON APPLYING RISK MANAGEMENT DALLAS FLOODWAY EXTENSION PROJECT

by
William Fickel[1]

GENERAL

Background. Since the 1960's, the Corps has undertaken a number of studies directed at developing a feasible, acceptable solution to the flooding problems within the city of Dallas, TX. In 1965, Congress authorized the Dallas Floodway Extension (DFE) project for construction as part of a basin-wide plan of improvement for the Trinity River and Tributaries. The recommended plan of improvement consisted of a combination of 18 .6 miles of flood control channels and 22 miles of floodway levees extending downstream of the existing Dallas Floodway Levees. The plan was designed to provide for Standard Project Flood (SPF) level of protection (880-year event or 0.125 percent probability of exceedance) within the protected areas and also designated 5000 acres between the levees for the development of a greenbelt-recreation area. The study area, depicted in figure 1, extends downstream from the Atchison, Topeka and Santa Fe railroad bridge to Interstate Highway 20 bridge, a distance of about 5 miles. The total cost of the recommended plan was estimated at $199.2 million (1997 prices).

The project was placed in an inactive status in 1985 because the local sponsor, the city of Dallas, was unable to fund its project responsibilities due to failed bond election. Following severe floods in 1989 and 1990, which resulted in loss of lives and widespread flood devastation, the local sponsor requested that the DFE project be placed in the active status. A reevaluation was initiated Fort Worth District in January 1991.

Between 1991-1994, the local sponsor constructed levees in two areas that historically had experienced repeated heavy flood losses. One levee was placed on the left bank of the Trinity River to protect a residential area referred to as "Rochester Park Area" and the other levee was placed on the right bank around the Dallas Central Waste Water Treatment Plant (CWWTP). The City designed both levees to offer SPF level of protection (0.125 percent probability of exceedance). Subsequent Corps hydrologic and hydraulic studies revealed; however, that the Rochester Park Levee and the CWWTP Levee offered only approximately 110-year (0.90 percent probability) and 140-year (0.71 percent probability) levels of protection, respectively. The earlier City design was found to have inadequately accounted for extensive upstream urban development changes which in turn had dramatically altered the river's runoff and downstream river stages.

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[1] Director, Civil Programs

Language in the Water Resources Development Act (WRDA) 96' contained provisions for credit reimbursement for the non-Federal construction of these levees if they were found compatible with the authorized DFE Project, including any subsequent modifications. In response to this legislation recent Corps studies strived to incorporate these locally constructed levees into the various alternatives considered, where engineering practicable. The local sponsor's cost for construction of these two levees totaled $27.0 million.

REFORMULATION ACTIVITIES

National Economic Development (NED) Plan Formulation. Corps reformulation activities conducted between 1991-1993 led to identification of the NED plan which recommended construction of an upper and lower 1200-foot bottom width swale (wide shallow ditch or overflow channel), extending over a distance of about 4.8 miles and included provisions for associated linear recreation features. Construction of the NED swale plan would eliminate 725 acres of mature bottom land hardwood forest land, requiring the purchase of 3,200 acres of lands at a cost of $13.5 million to mitigate the bottomland hardwood losses. Approximately 74 percent of the benefits for the NED plan would occur upstream in the area protected by the existing Dallas Floodway and 24 percent in the area currently unprotected. The estimated first cost of this plan totaled $50.0 million. Widespread opposition surfaced to the NED plan, primarily because of the extensive adverse environmental impacts associated with the project's construction. This led to the formulation of the more environmentally sensitive plans described below.

Chain of Wetlands (COW) Plan. First, two smaller swales were designed and relocated to reduce the destruction of bottom land hardwood forest lands as much as practical. Wetland features were then incorporated into the project features. This design, referred to as the COW plan, like the NED plan, provided for upper and lower swales. The upper swale would have a 400-foot bottom width and extend over a distance of about 1.5 miles and the lower swale would have a 600-foot bottom width and extend over a distance of about 2.2 miles. Approximately 287 acres of evacuated wetlands and tree plantings were added as environmental restoration features within the foot print of the project lands to gain environmental support. This plan reduced the impacts to bottom land hardwoods to 287 acres, requiring 825 acres for mitigation. A total of 265 habitat units would be generated from the environmental restoration features. Approximately 73 percent of the benefits would occur upstream in the existing Dallas Floodway and 27 percent in the area currently unprotected. The estimated first cost of this plan totaled $ 48.9 million.

Locally Preferred Plan (LPP). At the local sponsor's request, two earthen levees were added to the COW plan to gain higher levels of flood protection for residents living in currently unprotected areas. The east levee, referred to as the "Lamar Street Levee", would extend downstream from the existing Dallas Floodway levee to the city constructed Rochester Park Levee. The west levee, referred to as the "Cadillac Heights Levee", was added to the city constructed CWWTP Levee. Both levees, which offer SPF protection (0.125 percent probability

of exceedance), would have average height of 21 feet and span a distance of about 3 miles. The LPP would adversely impact 600 acres of bottomland hardwood lands, requiring 1400 acres of mitigation lands. Approximately 62 percent of the benefits for the LPP would occur in the area protected by the existing Dallas Floodway and 38 percent in the area currently unprotected. First Costs, annual costs, and annual benefits for each of the plans discussed above are summarized in Table 1.

TABLE 1
SUMMARY OF THE PROJECT ECONOMICS- FLOOD CONTROL ONLY

Item	NED Plan	COW Plan	LPP Plan
	(In millions of dollars)		
First Cost	$50.0	$48.9	$76.8
Annual Costs	5.5	5.1	8.7
Annual Benefits	13.6	10.5	11.7
Net Benefits	8.1	5.4	3.0
BCR	2.5	2.1	1.3

Project Status. A draft General Reevaluation Report, including an Environmental Impact Statement, is scheduled for release for concurrent policy and public review in October 1997. The report recommends designation of the Locally Preferred Plan (LPP) as the Federally supportable plan for cost sharing purposes. An exception is being sought from Assistant Secretary of Army (Civil Works) to allow full Federal cost sharing of the LPP. Congressional authorization is being sought in the upcoming WRDA 98' for the environmental features in light these features were not part of the plan originally approved by Congress in 1965.

RISK MANAGEMENT ANALYSIS

Analysis Performed. Through 1996, traditional procedures were used, relying on single points rather than probabilities to define frequencies, to calculate hydrologic values for with and without project conditions. The resultant hydrologic and hydraulic data were incorporated into the engineering and economic evaluations to calculate damage and benefit estimates and the concept of freeboard was used to account for hydraulic uncertainty in levee designs. Preliminary alternatives were first formulated following the procedures described above.

Selected alternatives were subsequently reanalyzed, in accordance with guidance contained in ER 1105-2-100 and ER 1102-2-101, first using a HEC "risk based" spreadsheet

add-on program that entitled" @Risk and later using the risk-based software program entitled HEC-FDA. Both the @Risk and the HEC-FDA programs incorporated Monte Carlo simulation techniques into the analysis to evaluate the hydrologic, hydraulic and economic uncertainties associated with the various alternatives investigated. H&H uncertainty parameters given consideration included water surfaces, frequency/discharges, stage/discharges, etc. Economic uncertainty parameters considered included stage/damage functions, threshold flood elevations, flood damages and benefits. Nearly 90 years of rainfall and flood records were available for use. These lengthy records aided in improving of the accuracy of the analysis, as reflected in the relatively narrow confidence bands of resulting regression equations.

The risk-based analysis undertaken in formulating the final plans focused on optimizing levee design performance, giving consideration to the value and types of development to be protected. Recommended levee crest design grades were selected through analysis of water surface profiles verses different levee heights. Similarly, risk-based procedures were applied to compute the estimates of annual damages, annual benefits, residual damages, and the probability of exceedance of various floods for the final plans investigated. The resultant levee failure probabilities under with and without project conditions are listed in Table 2. The local sponsor was faced with several challenges in selecting the LPP for the DFE Project. Most importantly was offering high levels of protection in downstream areas that had experienced reoccurring heavy flooding over the years. Secondly, the City desired to restore the existing upstream levee system to their original levels of protection. The upstream levees, which were constructed in the 1950's, were designed to have a probability of exceedance of 0.125 percent. Extensive upstream development throughout the watershed had reduced the probability of exceedance on these levees to 0.333 percent. Obvious tradeoffs were necessary in selecting the LPP because of social equity issues and because the types and design of flood protection measures (channels and levees) selected downstream inversely affected protection levels achieved in upstream areas. As reflected in the table, the local sponsor selected a solution that offered balanced, high levels of protection in all the affected areas.

TABLE 2
LEVEE FAILURE PROBABILITIES

Location	Existing Conditions	With Project Federal (NED) Plan	LPP Plan
	Probability of Exceedance (in percent)		
Existing DFE Levee			
East Levee	0.333	0.111	0.125
West Levee	0.142	0.111	0.111
Existing Unprotected Areas			
East Side of the River	N.A.	0.125	0.125
West Side of the River	N.A.	1.0	0.125

Note 1. The probability of exceedance of the Central Waste Water Treatment Plant is 0.2.

Defining Risk. At the request of the local sponsor's technical staff, the Standard Project Flood (SPF) event and other single frequency events (expressed in years) were used to communicate risk to the local decision makers and to the public throughout the study. The SPF event reflected a "simple "standard" that local decision makers and the public found more easily understandable to make comparisons on the project's performance. The SPF event was defined as the flood that may be expected from the most severe combination of meteorologic and hydrologic conditions that are considered to reasonably characteristic of the geographic region involved, excluding rare combinations. Subsequent risk-based analysis revealed that the SPF (defined to be approximately an 800 year event) to have a 0.3 to 0.08 percent probability of being equaled or exceeded in any year, and between 40 and 60 percent of the a Probable Maximum Flood.

PERCEPTIONS OF RISK AND UNCERTAINTY ANALYSIS

Corps Analysts Views. In early 1996, HEC staff conducted a one week Risk and Uncertainty Training Course in Fort Worth District. Selected interdisciplinary team members received specialized instruction on the use of HEC-FDA software program and applying risk-based methods. As one would expect some start up time was required for Corps team members to learn the necessary skills to perform risk-based analysis. Team members appreciation of the additional valuable analytical data gained from using a risk-based approach to make formulation decisions increased as their knowledge expanded.

Local Sponsor's & Public's View. As noted above, the local sponsor technical staff requested that probability results not be incorporated into the information provided to the public and others. Timing and lack of understanding of the merits of risk-based analysis contributed to this decision. The study had been underway over five years when risk-based analysis tools were introduced into the study process. Prior to their availability, traditional measures had been used exclusively to describe the project's performance. From the questions that arose during the study, it was apparent that many non-technical individuals had varying difficulties understanding the performance data even when presented in a more simpler form. Given these circumstances, the local sponsor believed changing to more complex, risk-based data would only lead to increased confusion. Other factors also influenced the LPP selection which could not be analyzed through computer simulation. One being, the sponsor's desire to address a sensitive local social equity issue, in that the project was located in an lower, social-economic area which the City had neglected over the years.

LESSONS LEARNED

Observations and Recommendations. The District learned a number of important lessons from performing risked-based analysis on the DFE Project. Observations on our experiences and recommendations to aid others in performing future risk-based assessments are offered below:

- Formal training is strongly encouraged for technical staff to be assigned to

perform risked-based analysis. Based on the District staff's experiences, undertaking advanced training measurably helped those involved to more efficiently perform the required analysis; to more capably understand and interpret the analysis results and make determinations on the relative importance of the findings; and to more easily convey the results to others.

- Corps staff found the HEC-FDA software program to be user-friendly. This included its ease to input data, to perform the required analysis, and to read and interpret the analysis results. Team members did request several minor modifications be made to the program software. Due to the infrequent reoccurrence interval for overtopping of the levees, the maximum number of interactions the program would accept had to be increased to 500,000 in order to obtain reasonable results. Minor adjustments were also made to allow more significant digits to input for the hydrologic data.

- Team members found that it was very easy to make simple errors which can significantly impact the analysis results given the mass of data being handled. An independent, thorough review of the program input and results is suggested to reduce the potential for these types of problems and improve the accuracy of the analysis results.

- District team members found working independently led to frequent miscommunication and led to an unacceptable number of errors slipping into the database. It believed that others would benefit if they did likewise.

- Education of local sponsors, the public, and others on the merits of incorporating statistical, risk-based approach into the formulation\decision process is a difficult issue all Corps face. Based on the District's experiences, one needs to start early in the process and continue to build on everyone's understanding as the study proceeds. In this regard, simplified charts, graphs and displays are needed. Risk based assessment procedures also need to be incorporated from the beginning and continued throughout the formulation process, if maximum benefit is to be gained by all.

- To conclude, the District gained invaluable knowledge from its first attempt in applying risk assessment procedures. Corps and local sponsor specialists acceptance of this new process, while taking longer than desired, grew along with their appreciation and understanding of the merits of using a risk-based approach. Some minor costs were required to train technical staff; however, early concerns and misconceptions that a risk-based approach would lead to considerably higher study costs proved false. One major benefit noted was that resulting statistical data generated from the risk analysis assured the decision process focused on critical formulation and design issues which often went largely ignored in the past. Continued emphasis on education of all the stakeholders on the merits of using a risk-based approach needs to be a top priority. Key to greater understanding, it is believed, is showing its value in making decisions, in the selection of project features, in making tradeoffs in costs of different designs, etc.

FUTURE DIRECTION REGARDING RISK ANALYSIS

by

Robert Daniel[1]

WHAT'S THE FUTURE OF RISK ANALYSIS?[2]

Introduction. I have heard this question posed on numerous occasions and in numerous locations. The humble usually begin with "who knows?" before they proceed to pontificate and the philistines say "who cares?" but immediately launch into an emotion laden tirade. How do you answer? Regardless of the group to which we belong our long answer is tempered by our personality, our academic training, the most recent policy decision, the time of day, the day of the week, the fullness of the moon, the amount of beer consumed, and positively the views exchanged with your boss regarding your performance appraisal. This IS NOT headquarters' answer, it is my answer as of approximately 1830 hours, Friday, 20 June 1997.

The Answer. On-the-one-hand it could be very bright but on-the-other-hand maybe not.

Discussion. Before I relate a couple of things that I believe need to happen and in fact will happen with or without formal risk analysis by the Corps of Engineers, I would like to set the stage with a little history to put into my perspective of how we got to where we are with such glacial speed which should help to explain why I believe what little I do.

WHAT'S THE HISTORY?

Selected Prehistory (pre 1985). EM 1120-_-___, 1948,[3] suggested sensitivity analysis regarding the discount rate. "The Green Book" 1958, suggested that "Adjustments for risk take account of the hazards and uncertainties that intervene between the commitment or investment of resources and the accrual of benefits." "Principles and Standards" 1973. "The basis for making a risk allowance in estimating the beneficial and adverse effects of a program or project should be clearly stated." "Principles and Guidelines" 1983. "The assessment of risk and uncertainty in project evaluation should be reported and displayed in a manner that makes clear to the decisionmaker the types and degrees of risk and uncertainty believed to characterize the benefits and costs of the alternative plans considered." Population at risk was informally introduced into

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[1]Economer, HQUSACE

[2]And anyone guilty by association.

[3]Last copy burned in 1990 Pulaski Building fire.

the Dam Safety program between 1983-5.

Selected Ancient History (1985-1992). It began with an exchange of memos between the ASA(CW) and the Chief with ASA saying: Ya'll done good on Dam Safety so lets extend these efforts by starting a research program and follow up with guidance on: "projection of with and without conditions; project design, schedule and scale; scheduling of rehabilitation; and, the regulatory program." The Chief, in response, proposed a cooperative effort on everything but the regulatory program. The ASA(CW) concurred in the need for a cooperative effort because "the magnitude of the task will be great." And "there is a need to provide a clear policy focus for the effort." Also identified at this time were three particular focus areas: "risk based analysis of flood control and navigation project design and scale; analysis of uncertainty in benefit projections and associated benefit based revenue streams and incorporation of this analysis into non-Federal financing strategies and construction scheduling; and incorporation of risk assessment techniques into the analysis of environmental effects of project plans." Again the Chief responded positively proposing a 3 point program of: research, guidance, and training. A small risk research program was identified, general guidance in the form of and EC was promulgated and 5 informal workshops aimed at sensitizing the impervious layer were held.

During this time a major rehabilitation program for the existing water infrastructure operated by the Corps was proposed but support from OMB was totally dependent on decisions and budget recommendations being supported by reasonable risk and reliability analysis. Thus it was that the research, guidance and training supporting this program was "fast tracked" consuming the majority of available resources. Techniques were developed, guidance issued, training sessions held and decision documents completed. Still risk research supporting a flood control program continued with development of useable methods which were incorporated into draft guidance and a formal training program.

Recent History (1992-1996). The research program continued to hum along producing large number of products to support the major rehab program as well as flood damage reduction. Numerous informal training sessions/workshops for both major rehab and flood damage mitigation have been held nationally as well as regionally and formal risk analysis training available in the Prospect Program has been very popular. The risk based Major Rehab guidance was updated annually for several years to include the new technologies being developed in the R&D program. It is now published in permanent form, ER 1130-2-500, with detailed procedures in EP 1130-2-500. Similarly, the risk based flood damage reduction EC (EC 1105-2-205) is now in permanent form as ER 1105-2-101 and EM 1110-2-1619.

The Answer. A focussed productive program pushed and supported from the top.

WHAT HAVE WE DONE? NOT DONE?

Discussion. Reviewing the original ASA(CW) memo, leads me to conclude that: 1) we have done nothing about the with and without project conditions from an economics perspective,

we have begun to treat the without project condition from the engineering standpoint e.g. PNP, PFP and hazard functions; 2) we have treated the project scale, e.g. top of levee, but are only beginning on project design; 3) scheduling of rehab work is driven by the risk analysis, i.e. value is dependent upon risk and consequences; and 4) we have done nothing on the regulatory program. Reviewing the second memo and our agreement with the ASA(CW) I conclude that: 1) we have been extremely clear about the value of and need for risk analysis to support the major rehab program but not quite as clear regarding flood damage reduction; 2) we've done a pretty good job on flood control scale but not design and we have accomplished nothing significant on navigation; 3) on the economics, we have again done nothing regarding the uncertainty of the benefit projections; and 4) we are just beginning to scratch the surface in the research of environmental risk.

The Answer. We have done: an outstanding job for some things, a not so outstanding job on others and some things not at all.

WHY HAVE WE DONE SO WELL AND NOT?

Discussion and Answer. I would argue that risk analysis for major rehab was so successful for several reasons all of which are related. First, there is not much perceived pork in major rehab. Any project being considered for major rehab exists and is currently producing benefits; true the rehab project may involve big bucks being spent in a congressional district but it is primarily to maintain the benefits that already exist. Second, OMB plays a stronger role in the go no go decision and OMB made it very clear from the beginning that there would be no major rehab program without meaningful analysis. You won't see many congressional adds for major rehab. Third, the major rehab program had strong support from the HQ proponent who also understood that without this analysis, there was no program. Further, the tradition in that functional area was that HQ was in charge of the program and in fact the proponent was in charge. Finally, there was good horizontal communication, at least at the HQ level, and each of the functional divisions understood their role. The vertical communciation within the proponent stovepipe, at least early in the process, left no doubt in anyone's mind that the game would be played using the risk analysis framework and taking full advantage of interdisciplinary/"interfunctional area" teams, incidently, the other functional areas found it to their advantage to participate.

For flood damage reduction, it is amazing that we have been as successful as we have. First, there is at least some puddin if not a full slab of bacon in a new flood control project. Second, OMB plays in new start recommendations but as a key part of the Adiminstration, OMB must be sensitive to the need for compromise. Third, there is no single flood damage reduction program proponent in HQ and all of the key executives, within the Corps at that time, were luke warm at best. The executive level push came from ASA(CW). Finally, there were good communications among the technical folks, at least at HQ, but there is no recognition that HQ is in charge of the program and there were, and still are, multiple stovepipes which are critical to getting the message understood, and incidently, not all disciplines/functional areas understood it

to be to their advantage to participate.

Regarding the other business practice areas, there is pork, the executive level has not shown any interest and there is only scattered interest among the technicians. Finally, the total amount of energy available is limited (see appendix).

WHAT'S THE RISK TODAY?

Recent Developments. The entire research program has been restructured. Ostensibly the intent was to match up with the 9 business practice areas. Early on this was apparently found to be not workable so we currently have 7 research areas, some of which are made up of 1 or more of the business practice areas, with some of the business practice areas not specifically identified, e.g. water supply or hydropower, the others research areas are cross cutting. One of the cross cutting areas, Water Resources Management, contains a program called, Risk Analysis. Unfortunately the current Risk Analysis research program is only a shadow of its former self, in the out years, it is to include only research that is generic and cuts across the narrow business practice areas. An example of this generic work might be the development of a risk-based evaluation and decision making framework for deep draft navigation and identifying the key sources of planning, engineering and operational uncertainty which need to be included. All R&D beyond this would then be accomplished in the Coastal Navigation & Storm Damage Reduction research area.

Current Events. (Or Non-events). The Civil Works R&D Committee has effectively blessed the current structure and allocation of resources. The guidance is essentially current with the outputs of the Risk Analysis R&D program and training is available but spasmodic. In June (97) the Planning Chiefs and the Engineering Chiefs conferences included an exercise on our ability to communicate risk information. An important conclusion from this exercise was that, with in the Corps, the "how to" of risk analysis is perceived to be less of a problem than the "what, when, why and where" of risk analysis.

The Answer. Possible demoralization of the troops, a program bordering on disarray and stagnation.

SO JUST HOW BRIGHT IS THE FUTURE?

Discussion. On the one hand it could be very bright but on the other it is absolutely pitch black. I believe it is as bright or dark as we, the corporate we, want it to be. I say this because I believe that people make their job what they want it to be and the same is true of organizations. Therefore, I must conclude that apparent darkness, demoralization, disarray and stagnation of the moment is largely caused by our own perverseness.

To deal with the future of risk analysis in isolation of the CW program would be

meaningless, therefore we must first address the CW program of the future. The traditional project-by-project model of plan, DESIGN & CONSTRUCT, and operate, if we must, is the pitch black future with or without risk analysis. In fact a full embracing of risk analysis can only cause a more agonizing demise by drawing out the pain and suffering. It will draw out the agony because it will facilitate the justification and delivery of ham hocks one at a time. That is why we must adopt a new model, or at least someone must, and will, adopt a new model.

So the bright future, my impossible dream, is that the CW program becomes a system management program. The requirements to make this happen and the implications are far to numerous to even think about listing. Suffice it to say that it will require a new culture, a couple of key components include the recognition: that the CW program is a program and not just a bunch of projects, that the taxpayer is the program customer, that resources are in fact limited, that wants are unlimited, that values change, that risk and uncertainty abound and must be dealt with in a rational way.

Closing. In the words of the Philistine, who cares? What's the relevance of this diatribe to the future of risk analysis? Assuming the new model, it means we must do lots to improve our analytical methods and communication techniques. The taxpayer is probably the most naive customer, most sophisticated customer and most difficult to please customer we can possibly have. This customer will never speak with a single clear voice. This customer will not likely trust the experts. This customer's values are continually changing. This customer will be more demanding with regard to understanding and participating in developing and evaluating: water resources goals; the costs associated with alternative levels of physical performance, economic outputs, and environmental outputs; tradeoffs; alternative estimates of value; timing; scale; and flexibility. In short, this means we need to be getting on with doing the things we haven't, developing tools or adapting our tools to be relevant for the total CW program and continuing to improve upon what has already been done. But even if we develop the improved tools, it won't do us a lot of good unless we improve our communication skills along with it. We have trouble communicating among ourselves, our naive customer certainly doesn't understand, our sophisticated customer asks things like "how safe is safe enough?" and wants to participate in making the decision. So our technican role is to perform the best analysis possible in a risk framework and communicate the results vertically and horizontally within the agency and to our customer. Thus a CW systems management program supported by a strong program of risk research, guidance and training is a very bright future indeed. On-the-other-hand ....

Answer. Obviously, I don't have a clue.

RISK-BASED ANALYSIS IMPLICATIONS FOR FLOOD PLAIN MANAGEMENT

by

Darryl W. Davis[1]

INTRODUCTION AND BACKGROUND

The foundation for application of risk-based analysis to Corps flood damage reduction studies was presented and discussed at a seminar held in Monticello, Minnesota in 1991 (HEC, 1991). The issue that gave rise to the seminar was that of levee freeboard, a well established engineering allowance for uncertainty in the stage of the design flood. A conclusion of seminar participants was that explicitly quantifying and subsequently integrating the uncertainty associated with various aspects of flood project studies into the analysis would provide improved project decision making as well as resolving the freeboard issue. In a nutshell, project features like levee freeboard would be abandoned in favor of explicit quantification of likely values and the associated probabilities. Draft guidance in application of risk-based was issued to Corps field offices later that year. Final guidance in the form of Engineer Regulations and Engineer Manuals have emerged in subsequent years (USACE 1996a and USACE 1996b).

One consequence of application of risk-based analysis is that more information is available about expected flood levels, flood level uncertainty, and project performance. Also, some traditional information is no longer developed. For example, it is no longer possible to assign a single value to the conventional performance index (level-of-protection) of flood damage reduction projects. Instead, expected values, conditional probabilities, and other like information are substituted. For Corps application in flood damage reduction project formulation, evaluation, and selection, these changes lead to more informed decision making. While project selection policies have not changed, better and more complete economic and engineering performance information is developed. The rub comes in that regulatory actions need explicit and non-controversial, criteria for which data is relatively easy and straight-forward to develop. The adoption of risk-based analysis by the Corps is criticized as upsetting the traditional regulatory system related to flood plain management.

The objective of this paper is to explore the relationship of risk-based analysis and flood plain management with the view to sharpening understanding of the issues and presenting the present flood plain management accommodation of risk concepts by the Corps. In this context, this paper is limited to issues related to flood risk data, flood plain delineation, Federal Emergency Management Agency (FEMA) certification, and Corps flood damage reduction project studies.

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THE ISSUES

The following table presents a summary of the issues related to risk-based analysis and flood plain management.

Table 1
Issues Related to Risk-Based Analysis and
Flood Plain Management

Issue Topic	Historic Context	Risk-based Context
Flood Risk Data, Presentation	Flow, stage, exceedance probability - tabulations	RBA[1] explicitly quantifies/ applies uncertainty in data
Flood Plain Delineation	Median probability flow - stage, Corps Ex. Prob. Q/S[1]	Near same; FEMA median prob., Corps RBA - Ex. Stage
Flood Project Benefits	Stage, flow, damage - integration for EAD[1]	Explicit uncertainty, better EAD; EAD distribution
Flood Project Performance	Level-of-protection, capacity exceedances	Expected exceedances, conditional probability
Flood Project Selection	Acceptable alternatives, net expected benefits	Same, improved estimate of net expected benefits
FEMA Levee Certification	Median flow, stage plus freeboard	Same, RBA - refined reflection of performance

[1]RBA - Risk-based analysis; Q/S - flow/stage; EAD - Expected annual damage.

FLOOD RISK DATA

Flood risk data are developed from hydrologic and hydraulic studies that determine flow-exceedance frequency, flood profile/stage, and areal extent of flooding. The basic information is extracted from historic flow records and applied in flow-frequency analysis and rainfall-runoff and river hydraulics calculations. The basic information is the same between contexts, the analysis is similar except that RBA explicitly quantifies uncertainty in stage and flow so that the resulting stages computed for flood risk tabulations and presentations includes the interaction between flow and stage uncertainties. RBA develops expected stage whereas the historic analysis can yield median probability stage as well as approximately the expected stage.

FLOOD PLAIN DELINEATION

Flood plains are delineated by intersecting water surface elevation profiles, normally computed from river hydraulics models, with terrain maps. Flood plains delineated for FEMA

flood insurance purposes are based on flow for the base flood (1% median probability event) and computed flood elevation for that flow. This is the standard policy no matter who delineates the flood plain (e.g. the Corps) since they are being delineated for FEMA mission purposes. Flood plains delineated by the Corps for flood benefit calculations in support of project studies are based on expected flood stage, either from flow developed using 'expected probability' and computed flood elevation for that flow, or expected flood stage directly as results from RBA. For all practical purposes, the expected flood stage as results from RBA and the flood stage resulting from computing flow via 'expected probability' then computing stage, are the same.

The application of risk-based analysis does not change the fact that FEMA and the Corps compute and delineate flood plains differently for reasons attributed to agency mission differences. FEMA takes the position that computing and delineating flood plains for the 'median probability' flood stage is appropriate for their flood insurance mission, and the Corps takes the position that 'expected probability' flood stage is appropriate for their mission for flood project studies. RBA simply results in expected stage due to incorporation of uncertainty directly in the analysis, and the result is in-effect, the application of 'expected probability' concepts. RBA neither solves nor further aggravates the differences in the two agencies viewpoints. Data in Table 2 introduced later contains information illustrating these differences.

FLOOD PROJECT BENEFITS

Flood damage reduction projects developed by the Federal government are subjected to an economic analysis to determine whether the proposed investment of public funds will yield positive national economic development benefits. Although there are some other complexities and issues, the basic approach of the analysis is to compute EAD for the flood plain to be protected, first without the project in place, then with the proposed project in place, and subtract the results to determine the expected damage reduction benefits. In the historic context , the EAD was computed by the Corps by forming for the condition of interest, an annual damage-exceedance probability function that is then integrated to compute the expected value of annual damage. This value is often referred to as average annual damage. Technical studies supporting this analysis include for each alternative of interest, developing flow-exceedance frequency functions via statistical analysis or rainfall-runoff models, stage flow relationships via water surface profile computations, and elevation damage relationships from flood plain structure inventories and flood vulnerability studies. The Corps applies 'expected probability' in the computation of the flow-exceedance frequency function development.

In RBA, the basic data are the same but additional data are developed for the basic relationships, and the integration to compute expected value is done by Monte Carlo sampling rather than simple graphical or numerical integration. The fact that RBA involves explicit quantification of uncertainties in the relationships is quite significant. The uncertainties must be derived (USACE, 1996) and incorporated in the expected value computations.

The outcome is that RBA estimates expected damage reduction benefits that are both different than the historic context (though not dramatically so), and improved. In addition, the

uncertainty in potential flood project damage reduction benefits is explicitly computed for use in project formulation and selection decisions. The inclusion of uncertainty in the EAD computations typically results in higher EAD values (Davis, 1991). The difference (e.g. damage reduction benefits) is usually, though not always, somewhat greater than the corresponding EAD computed in the historic context. Much debate about EAD computations with uncertainty is documented in the literature (NRC, 1995; Beard, 1997; Goldman, 1997; Stedinger, 1997).

For the discussion here, the view is that computing EAD and thus flood project benefits by application of RBA yields an improved estimate and provides valuable additional information about the uncertainty of potential project benefits.

FLOOD PROJECT PERFORMANCE

From a risk perspective, flood project performance was historically characterized by the concept of 'level-of-protection' (LOP). The LOP is the annual exceedance probability (often expressed as return interval in years) of the flood event resulting in incipient damage for the flood plain of interest. While there is some variation in interpretation of incipient damage in unprotected flood plains, it is most often taken as the flood event for which the stage just begins to cause significant damage; and for protected flood plains, it is the flood event that just begins to exceed project capacity.

Level-of-protection as a performance index is justly criticized because it only captures the exceedance probability of incipient flooding and does not capture other issues associated with project capacity exceedance. Nor does it reflect the uncertainty associated with flooding. It is widely used because it is simple and understandable (e.g. project provides 100 year protection). It is a matter of debate whether it illuminates or obscures the risk associated with flooding.

In RBA, there is less tendency to characterize project performance with the LOP because a richer set of information is available about risk performance - expected exceedances and conditional non-exceedance probability. While inverting the expected exceedances will yield an LOP looking number, it is more appropriately described as the average recurrence interval of flood exceedances.

The added information provided by RBA, conditional non-exceedance probability (referred to herein as simply conditional probability), has proven to be another useful descriptor of flood project performance. For example, we can now quantify the following: given that a 1% chance flood event occurs, what is the chance that it will exceed a given stage (e.g. top of levee). Similar information associated with other flood events is also easily developed. The fact that there is uncertainty about the ability of a flood project containing an event of interest was acknowledged in the past but was not here-to-fore quantified. Presenting conditional probability information up front is both informative (we know more about project performance) but also disquieting to those who prefer to assume that knowledge about project performance is more absolute. Some express the view that the additional information complicates decision making and is therefore not good. While we believe this information can and will contribute to better

understanding of project performance, flood professionals need to develop improved means of communicating risk concepts and information to local officials and flood threatened communities. Table 2 presented later, contains tabulations depicting information about performance characterized by conditional probability.

Other descriptors of flood project performance are needed such as residual damage (a series of single values) from floods; or floods, that exceed project capacity; or the expected residual damage resulting for all possible exceedances. Also, another measure of performance is difference in population at risk with and without the proposed project. RBA output is complementary with these additional performance descriptors.

FLOOD PROJECT SELECTION

The flood project development process includes the following steps: formulate likely alternative solutions, evaluate economic and other performance measures, array acceptable alternatives, and select the alternative that maximizes net national economic development (NED) benefits from the acceptable array. Local agencies may opt for larger/different plans (however they must pay the full cost of the increment over the NED plan) or smaller/different plans provided the Corps concurs that performance is acceptable. There is no cost share penalty for local preference of smaller (than NED) projects. A view has been expressed (it is not policy) that if local agencies select a plan that is smaller/different (and thus lower NED benefits), then they should contribute a higher percentage of costs since full NED benefits are not realized.

In the historical context, formulation and selections decisions were made on information presented as best estimates and derived expected values. In the RBA context, decisions continue to be based on expected values, but the values are improved estimates because uncertainty has been quantified and incorporated directly in the analysis. This is particularly the case for economic benefit estimates, as discussed previously. Not only is the expected value estimate improved, but the uncertainty in the expected value is quantified. In principle then, selection among the alternatives considering economic performance could consider degree of certainty in net benefits, perhaps favoring an alternative with lower expected benefits but less uncertainty over another alternative with higher expected benefits but also greater uncertainty.

A criticism voiced against RBA, particularly for levee projects, is that it would result in projects with lower protection levels, ostensibly because freeboard is no longer a feature, or that certification for the FEMA base flood would occur at lower elevations. (The certification issue is discussed in the next section.) Examination of Table 2, presented later, reveals no relationship between the FEMA certification elevation and the NED plan. The situation is just the contrary. As mentioned earlier, computed expected benefits are typically higher when using RBA (it stands to reason that greater uncertainty would result in higher expected values), than in the historical context. The tendency therefore is for the NED alternative to be larger (provide more protection) with RBA over the NED alternative in the historical context.

LEVEE CERTIFICATION FOR THE NATIONAL FLOOD INSURANCE PROGRAM

The consequence of the Corps adopting risk-based analysis for flood studies creates an interesting situation when levees are involved. Freeboard, a vertical levee height added to the design flood stage, was historically included to account for uncertainties in flood stages and levee embankment geotechnical performance. The amount of freeboard was normally a fixed amount, typically three feet, that was not varied to reflect uncertainties. With risk-based analysis, freeboard is no longer a feature since the uncertainties previously allowed for are now explicitly included in the levee sizing analysis. Also, no longer is there only a single valued representation of flood potential (for example 'the 100-year flood') since risk-based analysis more accurately reflects the uncertainty involved in flood estimates. Therefore, an issue associated with application of risk-based analysis is that of levee 'certification,' an important concept in administration of the National Flood Insurance Program of FEMA. The published FEMA policy for certification of a levee for protection against the regulatory flood (normally 100-year) includes freeboard in the criteria. This apparent inconsistency in the respective agency's perspectives regarding levees was the subject of discussions beginning in 1993 and continuing to the present. A detailed discussion of FEMA levee accreditation procedures is provided by (Gutherie et. al, 1991).

The discussions between FEMA and the Corps leading to the adopted policy dealt with the ramifications of acknowledging uncertainty, the need for continuity with past FEMA certification policy, and the desire to improve regulatory decision making. In broad terms, the alternative policies considered were:

a. Ignore risk-based analysis and continue with existing FEMA policy as published in CFR.

b. Base certification on expected flood elevation compared to top of levee elevation.

c. Adopt a conditional non-exceedance frequency target (e.g. 85% reliability) and base certification on comparison with top-of-levee elevation.

d. Devise comprehensive policy that incorporates continuity with existing FEMA policy and makes use of risk-based analysis results.

The policy adopted by the Corps, and concurred in by FEMA, is alternative d. It ensures that application of risk-based analysis is complementary with flood insurance program administration needs. The Corps policy was transmitted to the field by letter dated 10 April 1997 and is appended to this paper. Briefly, the policy is: when RBA data are not available - use existing FEMA levee certification policy; when RBA data are available, certify if have protection to at least 90% conditional non-exceedance probability flood stage (may be higher than existing FEMA policy would require) but protection need not be greater than flood stage corresponding to 95% conditional non-exceedance probability (may be lower than existing FEMA policy would require).

Data for a number of Corps studies provide information upon which to examine ideas and policies. Table 2 is an abbreviated version of the table that was the focus of much of the late-stage discussions between FEMA and the Corps leading to the policy adopted.

Table 2 is rich with information depicting the impact and implications of the adopted policy - it is worthy of study. For example, applying the adopted policy for the 13 stream/levee circumstances tabulated results in the following governing certification elevations: four by existing FEMA policy; four by the lower bound in Corps policy (levee would have to be higher than existing FEMA policy); and five by the upper bound in Corps policy (levee could be lower than existing FEMA policy). Also, of the eleven streams with NED plan elevations noted, there is no relationship between the FEMA certification elevation and the NED elevation; nine would be certified to FEMA with seven governed by existing FEMA policy and two by the lower bound of the Corps policy; and two would not be certified.

CONCLUSIONS

Concluding observations are:

> Application of RBA by the Corps has implications for flood plain management.

> The basic data required to perform RBA is the same as for the historic context; additional analysis is required to quantify uncertainty in flow and stage; and additional information is available for communicating about flood risk to responsible agencies and flood plain occupants.

> RBA does not materially impact the positions of FEMA and the Corps with respect to flood plain delineation - mapping for the FEMA flood insurance program is based on the median probability flood and mapping for Corps flood project studies is based on expected flood stage, just as the respective agency positions were before RBA.

> RBA improves flood damage reduction project benefit estimates and develops additional benefit uncertainty information for use in project selection decisions.

> Flood project performance information is improved with RBA by replacing level-of-protection with expected exceedances and adding conditional non-exceedance probabilities. Communicating performance information requires additional attention by Corps professionals.

> Flood project selection with RBA is very similar to the historic context in that the information and process are the same, but the information available are improved estimates and more complete.

> FEMA levee certification by the Corps has been substantially impacted by RBA. A policy has been developed and adopted through discussions with FEMA wherein the application of risk-based analysis is complementary with flood insurance program administration needs.

Table 2
Corps Levee Project Risk-based Analysis Data

General Information		Risk-based Analysis Data						
(1) Levee Project	(3) FEMA Cert. Elev. (Ft.)	(4) NED Plan Elev. (Ft.)	(5) NED Levee Expected Exceed.	(6) 1% Chance Expected Elev. (Ft.)	(7) Conditional % Chance Non-exceedance		(8) Elev. for Non-exceed. Freq. for .01 Event	
					FEMA (Col. 3)	NED (Col. 4)	90% Elev.	95% Elev.
1. Pearl R., Jackson, MS	44.6	47.0	1/770	41.8	97.6	99.8	43.4	44.0
2. American R., CA	49.1	52.0	1/230	47.1	91.9	94.4	48.5	52.3
3. West Sacramento, CA	32.2	33.5	1/670	29.6	99.9	>99.9	31.5	32.1
4. Portage, WS	798.3	797.0	1/10000	795.6	99.9	99.6	796.6	797.3
5. Grand Forks, ND	834.4	NA	NA	831.5	90.8	NA	834.3	835.2
6. Hamburg, IA	912.2	911.5	1/910	909.8	99.9	99.2	910.7	910.8
7. Pender, NE	1329.3	1330.0	1/380	1327.8	76.3	83.6	1330.9	1331.5
8. Muscatine, IA	560.8	561.5	1/330	558.8	90.1	94.4	560.8	561.7
9. Sny ILDD, IL	474.1	N/A	N/A	471.5	56.7	N/A	476.9	477.7
10. E. Peoria, IL	458.1	462.6	1/10000	458.3	45.3	99.5	460.7	461.2
11. Cedar Falls, IA	864.7	866.0	1/360	862.6	90.0	94.0	865.0	866.3
12. Guadalupe R., TX	57.9	56.8	1/110	56.5	87.2	76.9	58.4	59.5
13. White R., IN	715.0	713.2	1/250	712.3	98.0	86.0	713.5	713.9

Column Definitions: (3) 1% chance median discharge + 3.0 feet. (4) The NED plan levee elevation. (5) The expected annual exceedance probability of the NED levee elevation. (6) 1% chance expected elevation. (7) The % chance non-exceedance of a levee with the top elevation equal to that corresponding to the column noted given the 1% chance median annual event occurs. (8) The non-exceedance frequency elevation for 90% and 95% for the 1% chance median event.

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CECW-P/CECW-E 25 March 1997

GUIDANCE ON LEVEE CERTIFICATION FOR THE NATIONAL FLOOD INSURANCE PROGRAM

1. **PURPOSE AND APPLICABILITY:** This document provides guidance to be used for certifying levees to the Federal Emergency Management Agency (FEMA) for their administration of the National Flood Insurance Program (NFIP). This guidance does not affect plan formulation and evaluation procedures. It is intended to provide a consistent methodology for levee certification by the Corps of Engineers. This guidance applies to all Corps District and Division offices. Note that levee certifications are provided to FEMA at the District/Division option and within available funds.

2. **BACKGROUND:** By letter dated 21 March 1996, FEMA, requested that the Corps review its criteria for levee certification in order to ensure consistency in administration of the NFIP by FEMA. This concern has arisen as a result of the Corps application of Risk-Based Analysis (RBA) in flood damage reduction project formulation studies. FEMA's policy requires that levees be structurally sound, properly maintained, and have at least 3 feet of freeboard above the 100-year flood profile elevations before FEMA will recognize that the levees provide protection from the 100-year flood. The FEMA requirements are fully explained in 44 CFR, Chapter 1, Part 65.10 of the Code of Federal Regulations. The FEMA requirements include data and analysis submission requirements for design criteria (freeboard, closures, embankment protection, embankment and foundation stability, settlement, interior drainage), operations plans and maintenance plans. 44 CFR Part 65.10 also states that in lieu of the structural requirements and data and analysis requirements, a Federal agency with responsibility for levee design may certify that a levee has been adequately designed and constructed to provide 100-year protection.

Levee certification for NFIP purpose can best be explained as follow. FEMA may request a "levee certification" from the Corps by letter directly to the Corps District office. The letter normally contains language such as:

> "...Please provide this office with current certification as to whether the design and maintenance of this levee are adequate to credit it with 100-year flood protection. Please note that such a statement does not constitute a warranty of performance, but rather the Corps current position of the levee system's design adequacy..."

3. **POLICY:** The Corps will continue to work with FEMA to ensure that Risk-Based Analysis provides improved information for levee certification decisions. The following guidance and decision tree should be used until further notice.

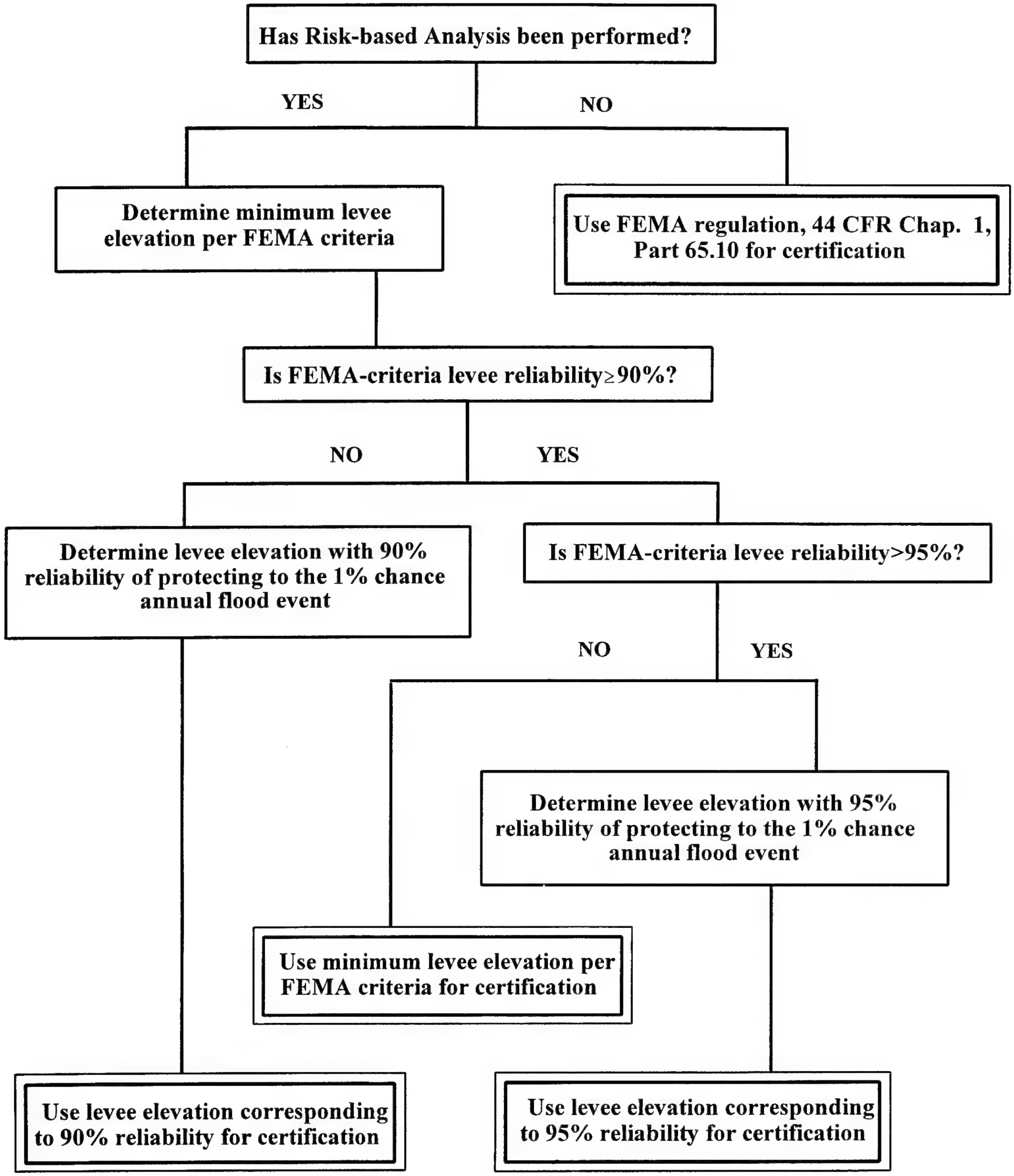
GUIDANCE ON LEVEE CERTIFICATION FOR THE NATIONAL FLOOD INSURANCE PROGRAM

a. **Existing Levees, No Risk-Based Analysis Available**: For certification purposes, the Corps should evaluate the levees based primarily on FEMA criteria contained in 44 CFR Chapter 1, Part 65.10 Thus, the general rule will be that if a levee will contain the median one percent chance flood, with three feet of freeboard, it should be certified as being capable of passing the FEMA base flood, as long as it is adequate based on a geotechnical and structural evaluation, as described below. Exceptions to the three feet of freeboard requirement may be pursued, based on the FEMA policy of permitting other Federal agencies responsible for levee construction to certify that levees will pass the FEMA based flood. Such exceptions should be based on careful evaluation of the hydrologic, hydraulic, structural and geotechnical uncertainties, and current levee conditions as discussed blow.

b. **Existing and Proposed Levees, Risk Based Analysis Available:** In these cases, output on project performance from the Risk-Based Analysis should be used to arrive at a decision regarding levee certification for FEMA. Existing and proposed levees will be certified as capable of passing the FEMA base flood if the levees meet the FEMA criteria of 100-year flood elevation plus three feet of freeboard, with two exceptions, as follows. When the FEMA criteria results in a "Conditional Percent Chance Non-exceedance" (Reliability) of less than 90% the minimum levee elevation for certification will be that elevation corresponding to a 90% chance of non-exceedance. When the FEMA criteria results in a reliability of greater than 95%, the levee may be certified at the elevation corresponding to a 95% chance of non-exceedance. For existing levees, the certification decision is also contingent upon a structural and geotechnical evaluation, as described below. For proposed levees, the geotechnical and structural issues are assumed to be accounted for during design and construction of the levees.

c. **Engineering Evaluation:** A geotechnical and structural evaluation will be used to determine the water elevation at which the levee is not likely to fail. In some cases, this water level will be the determining factor in the decision to certify the levee system. The procedures to be used in the evaluation of a levee system for NFIP levee certification should consist of an engineering evaluation to determine if the levee system meets the Corps design construction, operation and maintenance standards, regardless of levee ownership or responsibility. The District will examine available existing information and data, such as original design, surveys of levee top profile, levee cross-sections, records of modifications and changes, performance during past flood events, and remedial measures. It will also include a field inspection of the levee, structures, closure devices and pumping stations to evaluate the adequacy of maintenance. The engineering analysis should examine the project with respect to embankment stability, underseepage, through seepage, and erosion protection. Existence of closure devices will necessitate a review of the adequacy of flood warning time for the complete operation of all closure structures.

LEVEE CERTIFICATION DECISION TREE



FEMA Criteria = 1% chance median annual flood event plus three feet of freeboard
RELIABILITY = % chance non-exceedance given the 1% chance annual event occurs

BENEFITS OF RISK-BASED ANALYSES IN FLOODPLAIN MANAGEMENT
A FEMA PERSPECTIVE

by

Michael K. Buckley, P.E.[1] and Richard A. Wild[2]

INTRODUCTION

Throughout our history, Americans have settled next to rivers, streams, and other waterways because of the advantages the waterways offer in transportation, commerce, energy, water supply, soil fertility, and waste disposal. These benefits notwithstanding, the American attraction to settling along waterways does have its drawbacks. Floods have caused considerable loss of life and property, and they have disrupted more families, businesses, and communities nationwide than all other natural hazards combined. As we move into the 21st Century, we, as a nation, find ourselves at a crossroads in our use of floodplain areas. We may choose to use these floodprone lands for the primary purpose of economic development or we may take action to balance economic considerations with longer-term environmental and safety concerns for all citizens.

The Federal Emergency Management Agency (FEMA) has a vision for an effective way to balance the economic, environmental, and safety concerns. That vision is embodied in FEMA's "Partnership for a Safer Future." Under this vision, the United States' emergency management system will be built and maintained through a partnership of local, State, and Federal agencies; voluntary organizations; business and industry; and private citizens. These partners will focus on saving lives and property and reducing the effects of disasters regardless of their cause.

To guide its leadership role in this national emergency management partnership, FEMA adopted two mission-related goals:

1. Protect lives and prevent loss of property from all hazards; and

2. Reduce human suffering and enhance recovery after a disaster event.

FEMA plans to achieve the first goal through mitigation and preparedness initiatives, and plans to achieve the second goal through response and recovery initiatives.

To address the natural hazard posed by flooding, mitigation, preparedness, and response and recovery initiatives and activities can all be grouped under one two-word summary: Floodplain Management. This paper discusses FEMA's view of the future of floodplain management in the

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United States, the role the U.S. Army Corps of Engineers' risk-based analysis approach plays in the assessment of flood-control, and the benefits risk-based analyses may provide in enhancing the decision-making processes involved in wise floodplain management. This paper also provides an overview of FEMA's Disaster-Resistant Communities initiative.

FEMA VIEW OF FLOODPLAIN MANAGEMENT

FEMA defines "floodplain management" as a decision-making process that aims at achieving the wise use of our Nation's floodplains. Through wise floodplain management, we can reduce the loss of life, disruption, and damage caused by floods and preserve and restore the natural resources and functions of floodplains. To achieve the goals of floodplain management, Americans must adopt an approach that takes full advantage of all methods available to reduce vulnerabilities to damage while protecting and enhancing the natural resources and functions of the floodplain. Wise floodplain management would be achieved through

- Avoiding the risks posed by the floodplain;
- Minimizing the impacts of those risks when they cannot be avoided;
- Mitigating the impacts of damages when they do occur; and
- Accomplishing the first three while protecting and enhancing the natural environment.

CURRENT APPLICATION OF RISK-BASED APPROACH

If a levee meets certain requirements, FEMA credits the levee with providing protection from the flood having a 1-percent chance of being exceeded (base flood) on an NFIP map. These requirements are cited in Section 65.12 of the NFIP regulations. One of those requirements is that the levee have at least 3 feet of freeboard (the difference between the top of the levee and the base flood elevation). The freeboard requirement is, essentially, a safety factor used to account for, among other things, the uncertainties associated with the hydrologic and hydraulic analyses used to develop the base flood elevation.

Recognizing the variability in the uncertainties associated with hydrologic and hydraulic analyses, FEMA allows for exceptions to the freeboard requirement. In such cases, FEMA requires an assessment of those uncertainties. The U.S. Army Corps of Engineers (USACE) risk-based analysis provides a comprehensive assessment for considering such exceptions.

Deferring to the USACE expertise in the design and construction of flood-control structures, FEMA accepts certification from the USACE that a levee will provide base flood protection. With the advent of the risk-based approach, the language used in such certifications changed, causing some confusion. FEMA, giving guidance from the NFIP perspective, worked with the USACE to clarify "allowable exceptions" in terms of the risk-based approach. After investigating several applications of the approach, FEMA and USACE agreed that a 95-percent reliability level should be used as

guidance in certifying a levee with less than the required freeboard as providing base flood protection.

OTHER BENEFITS OF RISK-BASED ANALYSES IN FLOODPLAIN MANAGEMENT

FEMA sees the risk-based analysis approach extending beyond cost-benefit analyses for flood-control structures and becoming a useful floodplain management tool. Risk-based analyses can be used to establish floodplain management criteria and to measure the relative progress being made in reducing flood risks within a community. Communities can measure their own progress in reducing risk by applying the risk-based approach as storm water management and floodplain management practices are put in place. The difficulties associated with decision making when contemplating permitting requirements can be reduced significantly when the reliability of design criteria can be quantified. The standard "safety-factor" approach to such decision-making would change to a more risk-based approach.

The uncertainties associated with hydrologic and hydraulic analyses are recognized in the mapping and floodplain management efforts of the National Flood Insurance Program (NFIP); however, these uncertainties have not been quantified specifically in those efforts. Studies performed for FEMA in support of the development of NFIP maps range in scope from approximate analyses to determine approximate floodplain boundaries to detailed analyses using long periods of stream gage records, detailed topographic information, and model calibration from historic recorded flood events.

The reliability of the flood hazard information presented on an NFIP maps depends on the volume of data available to analyze a particular flooding source and the accuracy of those data. That is, a flood discharge estimate derived from a lengthy stream gage record generally is considered to be more reliable than an estimate derived from regression equations developed for a large region consisting of sparse streamflow data. Floodplain managers feel more comfortable allowing development up to a floodplain boundary developed using topographic maps with a 2-foot contour interval than a floodplain boundary developed using topographic maps with a 10-foot contour interval.

The reliability of the national floodplain mapping effort has been a continuous topic of discussion within FEMA, within the engineering community, and among floodplain managers since the inception of the NFIP. Most recently, the Technical Mapping Advisory Council has taken up the issue. Concerns have been expressed regarding the reliability of flood hazard information depicted on NFIP maps when the maps are used for management purposes without an understanding of the limits on accuracy imposed by the underlying amount and quality of data. Because they may not be familiar with those underlying uncertainties, map users/interpreters may mistakenly equate the precision depicted on the NFIP map with a higher degree of accuracy than is warranted.

Many communities, taking these reliability considerations into account, have implemented ordinances to create "buffers" between the flood hazard information available and the flood risk that may be present. These buffers have been defined by requiring the elevation of structures a certain amount above the base flood elevation depicted on the NFIP map and/or by restricting development

within a certain distance from the floodplain boundary show on the NFIP map. In practice, these buffers are consistent within a community and do not address the possibility that the reliability of the flood hazard information varies within the area covered by the NFIP map for the community.

Steps toward acknowledging the variability in the reliability of flood hazard information have been taken. These steps are demonstrated in several communities that require, for example, varying setback distances that depend on the magnitude of the base flood discharge. The risk-based approach allows the local floodplain manager to extend such attempts to the site-specific level. The approach provides a measurement of reliability on which floodplain managers can make confident decisions in their efforts to balance between the flood risk and the burden placed on the property owners who are compelled to protect themselves.

Having defined the reliability of flood hazard estimates, floodplain managers and property owners can make more informed decisions regarding balancing the costs of further study against the regulatory burdens placed on the property owner. Floodplain managers, working with the property owners, may decide that obtaining more detailed flood hazard information and performing more sophisticated analyses may be warranted if estimates are 40 percent reliable; however, they may decide such efforts are not warranted if estimates are 5 percent reliable.

The risk-based approach yields valuable information regarding future capital investments and/or plans to implement storm water management practices. Risk is the unit used to measure progress toward reducing hazards. Determining both the level of risk a community presently faces and the reliability of that determination will illuminate the more prudent direction to take in furthering hazard reduction efforts. If the reliability of the estimate of the present risk is relatively small, the benefits of various mitigation strategies may be obscured. It may be unwise to choose between different mitigation strategies when the benefit estimates fall within the uncertainty associated with estimate of the present risk. The prudent course in such situations may be to expend the effort necessary to increase the reliability of the present risk estimate.

FEMA has undertaken an initiative to create disaster-resistant communities. (This initiative is discussed in detail later in this paper.) Risk—or, more to the point, lack of risk—is the measure of "resistance." Disaster-resistant communities strive to reduce risks associated with all disasters, natural and technological. They accomplish this by avoiding hazardous situations where possible, mitigating hazards where they cannot be avoided, and continually improving their understanding of the hazards specific to the community. This is consistent with the concept of wise floodplain management cited earlier in this paper. A risk-based approach will be used to track and score the level of disaster "resistance" in a community.

The notion of risk and its subtleties will be a central theme of FEMA's Disaster-Resistant Communities initiative. The dialogue created by the initiative will broaden the views of officials charged with ensuring safe communities. As an example, consider the floodplain manager faced with the situation described below.

Five streams, each of which drains a relatively small drainage basin (5 square miles), traverse the

community. Historically, major flooding in the community has resulted from small, intense thunderstorms centered over one drainage basin. Although large floods have occurred on all five streams, the largest events are isolated on one stream or another. Two or more streams rarely experience large floods at the same time. Detailed flood hazard information for all five streams is presented on the effective NFIP map for the community. The flood hazard information indicates the flood frequency-magnitude relationship is essentially the same for each stream, and the reliability of the estimates is high.

The community's floodplain management goal is to ensure protection up to the base flood. A risk-based analysis for each stream indicates requiring that a structure be elevated 1.2 feet above the published base flood elevation will provide the desired level of protection, while allowing for complete development of floodplain areas that are not designated as being in the regulatory floodway.

If the anticipated development occurs, at the 1.2-foot elevation requirement, the community can expect flood damage with a frequency of once in a 20-year period (5-percent-annual-chance of occurrence). Thus, although an individual structure may enjoy the acceptable level of risk, the community as a whole does not.

Such a situation might cause confusion among those wishing to develop in the floodplain. A careful investigation and discussion of the risks associated with the individual structure versus the community as a whole should clarify the subtleties in defining risk and place the community's interest in safety into the proper perspective. As the Disaster-Resistant Communities initiative progresses, such discussions will become more common.

OVERVIEW OF DISASTER-RESISTANT COMMUNITIES INITIATIVE

Over the next 3 to 4 years, FEMA plans to encourage the establishment of disaster-resistant communities and to promote safer, more economically sound neighborhoods nationwide. To accomplish this major undertaking, FEMA will work with community, county, and State officials; private industry; the insurance sector, mortgage lenders, the real estate industry, homebuilding associations, and others. FEMA plans to accomplish this by focusing on the following areas of activity:

- Establish a Pre-Disaster Mitigation Fund. This fund will provide financial incentives for high risk communities to undertake mitigation efforts to protect their infrastructure and buildings before disaster events occur.

- Implement a Public/Private Partnership for Emergency Management. FEMA is exploring partnering opportunities with private-sector businesses for identifying disaster risks to communities, developing operating procedures for response activities, planning (short- and long-term), and executing training and exercise programs.

- Overhaul FEMA Public Assistance Programs. FEMA is planning to dramatically streamline

its Public Assistance Program procedures and thereby expedite a community's recovery after a disaster.

In addition to these new Agency initiatives, FEMA will encourage the concept of disaster-resistant communities by holding a series of town hall meetings in high-risk areas throughout the United States. The intent of these FEMA-led meetings is to focus public attention on mitigation and community responsibility.

FEMA also plans to promote the Disaster-Resistant Communities initiative by working with the private and public entities cited above to create model communities in high-risk areas. FEMA plans to select four communities that are committed to protecting their citizens, businesses, and infrastructure from the catastrophic effects of disaster events. Each community will address the hazard to which it is most vulnerable. The experiences of these communities will be used to begin the development of transferable models to the rest of the country.

CONCLUSION

In summary, the loss of life, disruption, and damage caused by floods can be reduced and the natural resources and functions of floodplains can be preserved and restored through wise floodplain management. To achieve the goals of floodplain management, Americans must adopt an approach that takes full advantage of all available methods to reduce vulnerabilities to damage while protecting and enhancing the natural resources and functions of the floodplain.

The USACE risk-based analysis approach has proven to be a useful tool in assessing the flood protection capabilities of levees. This approach provides a comprehensive assessment for considering exceptions to FEMA's levee freeboard requirement. However, FEMA sees the risk-based analysis approach extending beyond cost-benefit analyses for flood-control structures and becoming a useful floodplain management tool. Risk-based analyses can be used to establish floodplain management criteria and to measure the relative progress being made in reducing flood risks within a community. Communities can measure their own progress in reducing risk by applying the risk-based approach as storm water management and floodplain management practices are put in place.

The risk-based approach yields valuable information regarding future capital investments and/or plans to implement storm water management practices. Risk is the unit used to measure progress toward reducing hazards. Determining both the level of risk a community presently faces and the reliability of that determination will illuminate the more prudent direction to take in furthering hazard reduction efforts. Such efforts are a primary focus of the ongoing FEMA initiative to establish disaster-resistant communities.

A careful investigation and discussion of the risks associated with individual properties and structures versus the community as a whole should clarify the subtleties in defining risk and place the community's interest in safety into the proper perspective. As the Disaster-Resistant Communities initiative progresses, such discussions will become more common.

LOCAL PERSPECTIVE

OF RISK-BASED ANALYSIS

ON FLOODPLAIN MANAGEMENT ACTIVITIES

by

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THE CLIENT

There are two (or possibly three) client types that an engineer in private practice may encounter. The first type is the Private Client. This is normally a client who engages the engineer to perform a service which the client cannot perform because that client lacks the expertise, training or license to do the floodplain management analyses required for a particular project. The typical Private Client is a developer. A Public Client may be a city, county, special district, a state or a branch of the federal government. This client may hire the engineer for the same reason that a Private Client does, or the Public Client may hire the engineer to perform a service which the client does not have the workforce availability or the time to perform. This second type of client may also hire the engineer to be a "sacrificial lamb" or possibly to "be a shoulder to cry on". Analytical tools, procedures and results are of lesser importance when these two reasons are behind the hiring of the private engineer.

The possible third client type is that of Attorney. In this case the engineer may be hired by a private firm or a public agency to represent the interests of a party to a litigation. This type of client normally hires the engineer for expertise, but often expects to hire an advocate for the party's interests. While this may be sometimes expected it should not happen with professional engineers because their goal should be to hold preeminent the public's health, safety and welfare. When the engineer "tells it like it is" to the best of his ability that engineer is performing a true service to the client, the party represented and to the court and thus the public.

Whichever client type the engineer has when doing floodplain management analyses functions that engineer is expected to perform those analyses in accord with the current standards of practice at the place of performance.

RISK-BASED ANALYSES

The Standard of Care which must be met by a practicing engineer is to do the work with the care normally exercised by a typical engineer performing like services at the same time and in the same location. It is this standard by which the engineer must do his work or face the specter of

liability - both financial and professional. It is this liability which makes engineers so conservative in their approach to problem solving. If practicing engineers in the private sector had the immunities from liability that the Corps of Engineers enjoy there would undoubtedly be more explorations into scientific and mathematical crevices by the engineering community. It is interesting to contemplate and debate whether limitation of liability would in fact create the absence of the need for engineering registration or conversely would create the need for tougher, more meaning, more consistent licensure laws to better protect the public. Other viewpoints indicate that elimination of licensure laws but imposition of strict liability for engineers would better protect the public than the existing system of Standard of Care.

In any event the Standard of Care undoubtedly slows down the incorporation of new analytical procedures into day-to-day practice.

Coupled with the Standard of Care issue is the private practice engineer's lack of protection from the "law of large numbers". Unlike some large federal agencies which may do hundreds of projects in a year, a typical engineer in private practice may do only a handful of floodplain management protection projects in a career. While statistical techniques work on the average, if the "outside of the average" hits during your watch, you are in for some rough sledding through second guessing, self doubt, loss of professional reputation and likely loss of future revenues. There are a couple of examples which come to mind when thinking about the conservative nature of engineers.

The first example is from the construction history of Hoover Dam. According to an account in *Hoover Dam, An American Adventure*, by Joseph E. Stevens, after the diversion tunnels had been started on both sides of the canyon there was a flood on September 26, 1931. The levees constructed in front of the portals to the tunnels held and there was no damage. However, in February of 1932 when the tunnels were well along inside the rock abutments, a warm rain fell on an early, heavy snow pack in the watershed along the Virgin River. The flood of February 9, 1932 did not enter into the tunnels due to human intervention involving sand bagging to bolster the levees. However, the flood of February 12, 1932 was much greater. It tore into the levees, breached them, flooded the partially completed tunnels and left a set of diversion tunnels aquiver with gelatinous muck.

After the September flood no high water was expected until next summer's flash flood season when the tunnels would have been completed and the coffer dam would have began construction.

The second example is that of the coffer dam sizing that we have all done as part of our engineering economics course. Remember the problem: size the coffer dam to minimize the expected cost. Costs are due to damage and to construction. The higher the dam the more the construction cost but the lower the expected damage. We have all done this problem and felt good about the result.

In the first example there was a failure and a cost even though the engineer had figured that the summer thunderstorm floods could be protected against. For the engineering economics problem the answer we all came up with would work well on the average. If the engineer does a lot of coffer dams he may get a failure once in every fifty or so but hopefully by the time this happens that

engineer's reputation for prudently designing coffer dams would probably be in place. If, however, that engineer's first coffer dam failed just like the levees in front of the portals to the diversion tunnels at Hoover Dam, that engineer might never get another chance to design a coffer dam. Therefore, engineers act conservatively, maybe more conservatively than statistics would dictate because of the awesome responsibility to protect the health, welfare and safety of the public.

THE REGULATORY CLIMATE

When doing floodplain management analyses for a client, the engineer is often constrained by the regulatory climate of time and place. Local ordinances set up standards of performance which the local citizens wish to have implemented to provide for their health, welfare and safety. Generally the engineer must adhere to these standards except in the case where the standards are believed to be inadequate and the engineer must design to a higher standard.

The local staff may have a different interpretation of local ordinances than does the practicing engineer. In this case negotiations may have to be undertaken to satisfy staff of the propriety of the engineer's analysis. Depending upon the staff make-up and expertise, this task may range from very simple to tedious, nerve-racking and technically complex.

Besides local ordinances there are federal and state statutes with which the engineer must comply. Typically encountered are the FEMA regulations which the engineer attempts to understand and comply with before submitting applications to FEMA for letters of map changes.

Last but certainly not least is the decision-making body. Often the engineer must present the results of floodplain management analyses to such a body for an official acceptance or rejection. These bodies are usually made up of non-technical people (often innumerate) who are highly educated, articulate, literate and often aggressive. The questions that they pose will usually challenge an engineer to think about the project in a totally different manner. Often these sessions will take on the air of a college lecture if the engineer carefully explains the results in terms that laypeople must strain to comprehend. The bottom line here is the acceptance of a line on a map, the size of a culvert, the height of a levee, the depth of a channel, the height of a dam or the length of linear park. No matter how much probability and statistics goes into the analyses of the project, the final outcome becomes a finite value which decision-makers can accept or reject. Now, the engineer can couch the results in as many disclaimers as necessary, but the final outcome will be an acceptance or a rejection of a line on a map, the size of a culvert, ...

EXAMPLES

Client type, Standard of Care and the regulatory climate all combine to constrain the practicing engineer from implementing risk-based procedures. Some recent examples of some of the limitations are described below.

Level of Protection. While in theory the cost of a given level of protection should be balanced against the expected average annual damages, in practice a number of things constrain the

engineer to provide a 100-year flood level of protection for urban land uses. The only urban uses which may have different, higher levels of protection are hospitals, sewage treatment plants and other vital public facilities. Nuclear power plants are usually protected to the probable maximum flood level. These levels are dictated by regulations: federal, state and local. As a rule, floodplain management engineering does not even look at alternative levels. Adherence to the regulations is all that is expected and generally all that is done for a particular project. Risk-based analyses are virtually absent in determination of level of protection for urban land use projects.

Freeboard. This one project parameter has seen some very interesting applications in floodplain management. Certainly everyone familiar with floodplain management knows of FEMA's dictates when considering freeboard for levees; but other than levees there is no FEMA regulation regarding freeboard for any other type of floodplain damage mitigation project. This can be quite disconcerting to the practicing engineer when there is no freeboard requirement in situations where there is a floodway designation. The floodway designation, as you no doubt know, usually allows for a one-foot rise in water surface elevation due to fill along the fringe areas. However, the regulations allow first floors to be built at the water surface elevation prior to the floodway designation. This means that some structures may be constructed one foot too low when complete build-out occurs.

1) **Some Like It Hot!** One Special District which is responsible for flood control and water supply routinely requests that first floors be constructed at least three feet above the FEMA regulatory water surface elevation: one foot for freeboard, one foot for future land use placement (the floodway effect), and one foot for increases in peak discharge. Unfortunately this Special District has no land use authority and, therefore, has no say in first floor elevations. Also unfortunately this Special District usually requests that development utilize detention basins so that water surface elevations will not be adversely impacted, thus negating the argument for one-foot increase in first floor elevation due to the peak discharge increase. This District appears to be slow-growth in philosophy and appears to attempt to act as a halt to residential, commercial and industrial development.

2) **Others Do Not!** The largest City within that Special District has an opposing view of freeboard. None is required. FEMA does not require it, so that City's ordinance does not require it; staff and the Council feel that the City burdens development enough already with current regulations and does not impose anything beyond the minimum standard for floodplain management. The City is pro-growth, particularly the industrial type of development.

3) **The View From the Bench**. Attorney's have a ball with the freeboard issue. The usually framed question goes something like: "will the levee fail when the water enters the freeboard range or is the project expected to pass all the flow up to the top of the levee?" Certainly many attorneys have a real knack for framing questions in black and white when in reality they are actually a shade of gray. Often if something is not "right" then it is obviously the converse - "wrong".

In the expert witness testimony about freeboard there appears to be a great gulf of opinion about what freeboard is and how projects are expected to react when operating in the freeboard range. The new terminology of risk-based analyses which uses "probable failure elevation" or some such terminology has inadvertently added a degree of specificity to the operations in the freeboard issue. Now it is commonly assumed that when the water level rises to this "probable failure point" the project will fail and if it is a levee project the consequences may be catastrophic. Any deferred maintenance which can cause the water level to reach that "probable failure elevation" can now be more easily blamed for levee failures. When millions of dollars of damages are at stake and when the damages are being paid for not by the project designer or constructor but by the operator of the project, this type of terminology is not looked upon with favor by many engineers.

Hydrology. A Special District for flood control long ago had a hydrologic procedure which was based on the unit hydrograph/design storm methodology. The District decided to utilize more up-to-date statistical procedures to better evaluate the flood potential of streams under its jurisdiction. A lengthy statistical process produced results which were much, much greater than those in use from the unit hydrograph/design storm procedure. The District was convinced that these new values were superior and began using them in earnest. After twenty years of construction and planning and struggling with local cities and environmental groups the District re-evaluated its procedures because it now had twenty more years of data and there were have been some major advances in statistical techniques during that time period. The new results came out much, much lower than the old values but in line with the older unit hydrograph values. What to do!

This dilemma points out a potential problem. The problem is not that of the variability of statistical information; after all, that is statistically expected. It points out the problem with consistency of advice. The public expects safety from floods and it expects the public agency responsible to do a competent, workman-like job. When widely fluctuating values are published many people and decision-makers become nervous and suspicious of the results and the developer of the results. The real dilemma here is whether that District should keep its older, higher values and continue its flood control mission for another twenty or so years with these more conservative values and then re-evaluate or whether it should go with the latest statistical results, cut its maintenance program which attempts to keep roughness values in line with design, build smaller flood water conveyance facilities and make it more difficult for future floodplain managers to increase conveyance capacity should statistical results show much higher values when re-evaluated in twenty years.

Floodplain Delineation. Besides the typical riverine floodplain delineation analysis which must end up with a line on a map, there are other floodplain delineation problems which also end up with lines on maps but which make use of vastly different hydrologic and hydraulic procedures. One such problem is that of playa hydrology and in particular predicting the 100-year water surface elevation in the lake bed of such an enclosed drainage basin. A procedure that was utilized was that of predicting the storage in a water supply reservoir but in this case the only potential use of the accumulated water was evaporation. Through statistical techniques the monthly mean, standard deviation, skew and lag-one serial correlation coefficient were predicted for this watershed using

linear regression with the seven closest stream gages. A random process was then utilized to select new sets of parameters and generate 2000 years of simulated monthly runoff/evaporation/storage traces. This Monte-Carlo procedure was then run hundreds of times to develop a statistical variation of the 100-year water surface elevation.

Even though this was considered to be a good application of statistical procedures and of a risk-based analysis for an unusual floodplain management problem, it was rejected by FEMA upon application for a letter of map amendment in favor of a 10-day design storm calibrated to the 10-day 1986 flood, coupled with an antecedent 2-year, 24-hour flood inflow to provide for carry-over storage and antecedent storms. The results were identical to those of the risk-based analysis so the client was satisfied.

CONCLUSION

Regulatory Rules!

Well almost. A combination of current floodplain management regulations at the local, state and federal levels coupled with engineering judgment is more correctly what rules the current practice. The Standard of Care is very important to the practicing engineer and is routinely discussed by these practicing engineers on individual projects. Any risk-based analysis is generally done only on an intuitive basis in a manner faintly similar to some of the built-in safety factors incorporated in development of the Standard Project floodplain.

The risk-based approach to floodplain management analyses appears to hold the hope of a better level of understanding of the risks in decision-making in the floodplain. However, in the final analysis the engineer's individual judgment will still be required to place a specific line on a map, or specify the size of a culvert, or identify the height of a levee. That engineer must usually stand before a body of decision-makers to explain and if necessary defend that decision. Ordinary citizens depend upon engineers and their judgments before investing their life savings and even their lives and, therefore, engineers should (and normally do) use good analytical tools in their work. Currently, however, there is little or no formal use of risk-based analysis tools in local floodplain management engineering.

PANEL DISCUSSION
RISK ANALYSIS IN FLOOD PLAIN MANAGEMENT
Challenges for the Future

By Ken Kwickl

1. Introduction

The purpose of this presentation was to summarize the status of risk-based analyses development and implementation in the Corps of Engineers. The presentation is primarily based on information presented in papers during the previous two days of this workshop. The "challenges" presented here are also based on the author's perceptions of acceptance of risk analysis within the Corps, use of the techniques, and comments and concerns of various entities outside the Corps of Engineers.

2. Challenges for the Corps of Engineers

a. Challenges for the Districts

Corps of Engineers Districts and Divisions must continue to be educated on risk-based technology. Early on in the implementation of risk analysis, the learning curve was steep, and although it has leveled off to some extent, there is still much that can be learned and improved upon. Because risk analysis techniques are being occasionally revised and continually improved, the process of learning must also continue.

There has been a perception that the Corps plan formulation process in some cases is being done in reverse. Project sponsors request that a minimum "level of protection" from the 1% annual exceedance event be provided, and the risk analysis is performed to justify that size project. Based on the presentations by the several Districts in attendance at this workshop, this perception is not a reality. The process followed by these Districts - formulate alternatives, identify Federal interest, identify the appropriate level of Federal investment, then evaluate locally-preferred plans and FEMA certification issues - is the correct process. It is important to remember that the although the sponsor plays an important role is development of the recommended plan, the Corps must identify alternatives based on the NED criteria first.

Most discussions during this workshop have focussed on risk analysis for levee and channel projects, and little has been mentioned about nonstructural measures. Nonstructural measures never seem to be emphasized in Corps planning, using risk analysis or otherwise. In the past, this has been due in a large part to the lack of interest from the local sponsors. However, times are changing, and there is more local acceptance of these valid flood damage reduction measures. Districts should ensure that nonstructural measures are fully considered in the plan formulation process.

Much has been discussed this week concerning FEMA, the National Flood Insurance

Program, and certification of levees for FEMA mapping needs. Those discussion do not need to be repeated here. What must be emphasized is the need for full coordination with FEMA during the Corps planning/design/construction process, to ensure that NFIP considerations are an integral part of that process.

b. Challenges for the Corps Labs

The Corps labs - HEC, WES, and IWR - have done an excellent job of developing and enhancing risk-based concepts for use in the Corps plan formulation process. The labs continue to work to improve risk-based procedures and to develop tools to aid the Districts in accomplishing their missions. In addition, from what we've heard this week, the labs have been major players in several important flood damage reduction studies, assisting the Districts in completion of feasibility studies using the risk-based approach. The challenge facing the labs is to work toward integration of other uncertainties such as those involving cost estimation, and structural and geotechnical analyses, into the risk-based procedures. The challenge facing headquarters, and ultimately the labs, is to continue to justify and commit adequate funding for these efforts.

3. Challenges for the Federal Emergency Management Agency

As mentioned above, much has been discussed this week concerning FEMA, the National Flood Insurance Program, and certification of levees for FEMA mapping needs. It is clear that there will always be differences between the Corps flood damage reduction program and the FEMA mission of disaster assistance/recovery and flood insurance. FEMA has worked very closely with the Corps in developing the procedures for providing Corps certification of levees to FEMA for flood insurance mapping purposes. What must be emphasized is the need for full coordination with FEMA during the Corps planning/design/construction process, to ensure that FEMA considerations are an integral part of that process.

Beyond that, a suggested challenge for FEMA would be to give serious consideration to use of risk analysis for flood insurance program endeavors. FEMA should consider requiring flood insurance even where flood damage reduction projects have been constructed to provide protection from flooding. FEMA should also consider using actuarial flood insurance rates that reflect the actual risk at a given location. By incorporating risk-based concepts in the mapping process, while retaining the "100-year" flood as a base flood, zones of true risk could be depicted on flood insurance maps, with insurance rates consistent with that risk being applied. Another area where risk analysis may be applicable is in the review of locally submitted grant applications for flood mitigation grants. Risk analysis may be an appropriate tool for evaluation and prioritization of these applications.

4. Challenges for the Association of State Flood Plain Managers

The Association of State Flood Plain Managers plays an important role with the Corps of Engineers. The ASFPM meets with OMB and testifies to Congress, playing an active part in

defending the Corps budget and legislative initiatives. The ASFPM is a network of professionals dedicated to those same things that the Corps is dedicated to: flood damage reduction, environmental restoration, and other water resources issues. If the ASFPM has serious difficulties with efforts we have underway, we would do well to listen carefully to them and work to resolve those difficulties. The ASFPM should continue in its role as coordinator/mediator for technical and policy issues common to FEMA, the Corps and ASFPM members.

The ASFPM has the challenge of continuing to educate its members on the use of risk-based analysis. The Corps has hosted several workshops for ASFPM members on risk analysis and both the Corps and ASFPM should continue to look for opportunities to continue in these efforts.

5. Challenges for our non-Federal partners

The biggest challenge facing our non-Federal partners is to practice sound flood plain management. Understandably, there are many pressures being placed on the sponsors to not do the "right thing." Better education of the public is one major step towards relieving some of those pressures, and output from the risk-based approach may provide the non-Federal sponsor with important information to be used for this education. Sponsors should also consider using risk-based analysis output in conjunction with FEMA criteria and regulations to resolve flood plain issues.

6. Challenges for all parties

The Corps must continue to encourage open dialogue with FEMA, ASFPM, states, local governments and the private sector on risk-based analysis issues. We should all strive for full coordination in these and other issues to ensure that the Corps procedures are developed and used in an appropriate manner.

Risk Based Analysis
Implications for Floodplain Management

by

Doug Plasencia, P.E.[1]

In the early 1990s, risk based analysis methods were being developed by the US Army Corps of Engineers. During this time, the Association of State Floodplain Managers became increasingly concerned with this departure in design methodology. In part this concern was fueled by:

a. The basis for change, as communicated to ASFPM, was to satisfy an OMB desire to justify why significant amounts of money were spent on freeboard.
b. Initial results that indicated that with risk based methods that many existing levees would have been built to a lower elevation, during a period of time when levee failure and catastrophic damages was in the daily news.
c. A dramatic change in approach where we were moving from saying that uncertainty could not be quantified but based on engineering experience we should use a safety factor called freeboard; to an approach that said we can now quantify uncertainty through statistical simulation of numerous independent factors that impact performance.
d. Difficulty in communicating method impacts on Non-Corps applications.
e. Early FEMA acceptance of risk based analysis with little consideration of how "level of protection", e.g. 100-year flood, relates to risk base terms such as the conditional non-exceedence (CDN or reliability) or the exceedence probability.

In essence communications and levels of trust were marginal. However, currently (October 1997) it appears that there can be considerably more comfort with risk and uncertainty methods providing the following is considered and incorporated.

1. Communications - A significant factor influencing ASFPM's early reluctance was the inability to communicate the shift. To maintain separation between traditional methods driving most floodplain management and stormwater management programs and to meet internal Corps of Engineer missions for economic analysis there always has been and will continue to be a reluctance to use level of protection as a descriptive output. In part from a risk base perspective this is due to the fact that we really can not ever report an absolute level of protection with 100% confidence. Risk base substitutes for level of protection the Exceedence Probability that is further qualified by the CDN or reliability. While from an academic perspective this makes infinite sense; from a program management perspective this opens the door for significant confusion and potential abuse. The

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[1] Kimley-Horn and Associates, Inc., Phoenix, Arizona and
National Liaison on Mitigation Policy, the Association of State Floodplain Managers

ASFPM strongly urges that the level of protection concept be sustained and as needed its definition modified to include risk based terms as appropriate. For this recommendation to be viable there is a need to mesh recommendation #2.

2. CDN or Reliability - Inherent to the exceedence probability is the CDN or reliability factor. The CDN when linked with the exceedence probability provide a complete view of "level of protection". Based on these linked results it is feasible to report the estimated reliability for a given structure to pass various return period flows. For example the same facility may have a 99% reliability for passing a 10-year flood, a 95% reliability for passing a 100-year flood, an 85% reliability for passing a 200 year flood, and a 60% reliability for passing a 500-year flood. While this is something that can be quite useful for performing robust economic analysis, it becomes confusing and difficult to describe for the practitioner or the regulator that is attempting to sustain a required level of protection. For uses of the method that are attempting to report "level of protection" (now defined to include both exceedence and CDN), it is necessary to establish a minimal level of reliability where a given level of protection can be ascribed. This is similar to , but need not be as complex, as the current certification process developed by FEMA and the Corps. The ASFPM strongly urges that an expert committee be conferred that would assign minimal levels of reliability to various structure types , field situations, and that would include state definitions of protection levels. For example perhaps levees would maintain 90 or 95% reliability for all urban applications, and perhaps would maintain a lesser level of reliability for nonurban applications or applications that would be for a lesser level of protection.

3. Training - There is an absolute need to begin to communicate risk based analysis to practitioners. <u>This communication process should not occur however prior to coming to agreement on the new definition for level of protection</u>. At that time the education can be conducted in two phases. Phase one is a simplified explanation that should assure users and community officials that there is an improved method of accounting for uncertainty when developing estimates of level of protection. Phase two would be training in the application of risk based analysis.

4. Peer Review and Black Box - The probabilistic background of risk based analysis exceeds the educational level for many practitioners, and exceeds the comfort level for most practitioners. To assure the validity of the approach it is essential to occasionally use independent research bodies that can investigate the approach and confirm that the method reasonably accounts for uncertainty in design. The National Academy of Science review called for in WRDA 96 is a good example of how these reviews could be approached.

   In addition there is a need to develop some simplified tools that allow for the user of risk base to validate whether the results are within the range of reasonableness. These estimates are not intuitive, and as with any modeling exercise is an important component for quality control.

5. State Lead - It is essential to understand that the management of the nation's floodplains is a state and local government responsibility. As the Corps proceeds with the implementation of risk based analysis it is essential to keep in mind that when State Laws and Standards exceed federal criteria that designs should be accomplished that meet these designs. This is not to suggest that if a state criteria leads to a project that exceeds the federal "interest" that the increased costs automatically become a federal cost; but this is clearly an issue that would warrant ongoing work between the Corps, the States, and Congress.

With the accomplishment of the above recommendations and continued acknowledgement from the Corps of Engineers that risk based methods must be implemented with a careful eye towards impact on state and local floodplain management programs, the ASFPM is becoming optimistic that a tool is being developed that can improve our ability to quantify and manage flood risks.

EVALUATION OF PERMANENT FLOOD PLAIN EVACUATION IN THE CONTEXT OF WATERSHED MANAGEMENT PLANNING

Michael Krouse

With the convergence of watershed management initiatives, the Corps environmental restoration program and a movement toward permanent flood plain evacuation measures the Corps has a unique opportunity to take a fresh look at how we evaluate flood damage prevention measures. In the context of comprehensive watershed management planning and for environmental restoration. Consequently, the US Army Corps of Engineers Institute for Water Resources commissioned a study to look at alternative ways to formulate and evaluate plans for permanent flood plain evacuation. Flood plain evacuation is normally not economically justified under the Principles and Guidelines and as a result WRDA 96 directed a study be conducted to examine impediments to the evaluation process. That study is underway under IWR's policy studies program. A concurrent study undertaken by IWR research program is to examine how, given the economic constraints of the current P&G, flood plain evacuation might be combined with possible environmental outputs and as a integral part of a watershed management plan to solve traditional flooding problems and other economic and social concerns. Follow on studies will attempt to provide examples of how tradeoffs among outputs, traditional monetized and non-monetized (environmental outputs) can be determined and used in the formulation and evaluation process on a watershed scale. Included will be a consideration of the complicated cost sharing issues which arise with multiple outputs which are monetized and those which are not. Obvious risk analysis implications related to uncertainties about flood prevention effects and environmenetal outputs both on site and off site.

Selected major findings of the IWR funded study, *Evaluation of Floodplain Permanent Evacuation Measures: An Alternative Approach for the US Army Corps of Engineers* by Leonard Shabman, Ann Riley and Gerald Stedge, are summarized below for the workshop participants consideration.

DEFINE A COMPREHENSIVE PROTOCOL

spatial scale large enough to evaluate the full range of hydraulic, hydrologic and ecological influences of any alternative, including the permanent evacuation measure , on the economy and the environment.

definition of planning problems and opportunities that recognizes multiple outputs from all water and related land management alternatives, including the permanent evacuation measure;

plan formulation that incorporates permanent evacuation as a measure, along with other structural and non-structural measures, into a complete alternative capable of addressing the full range of problems and opportunities in the watershed;

evaluation of alternatives using measures appropriate to the multiple decision criteria of economic efficiency (NED), environmental outcome, fiscal impact, and equity;

collaborative decision making by government and non-government organizations who select a preferred alternative in consideration of measured tradeoffs among decision criteria.

shared responsibilities across governmental and non-governmental organizations for the institutional and financial requirements for implementation.

Seek Common Understanding of the Protocol Throughout the USACE

The USACE has moved its policy and programs to align closely with the new national themes of ecological restoration and watershed management. These movements will facilitate the adoption of the comprehensive protocol for permanent evacuation measures. However, even though the agency has issued guidelines for restoration planning and policy, the applications in the field, and the relationship of the new restoration programs, to current USACE planning rules and decision processes is not well understood. Because the comprehensive protocol is the logical result of the changes set in motion by the EC, the USACE needs to focus significant resources on fully exploring the implications of the guidance and for assuring that the implications are understood and accepted at *all* levels of the agency. Otherwise there will continue to be barriers to a USACE consideration of the full merits of permanent evacuation and practice will continue in conflict to policy.

Recognize that Restoration Describes a Type of Water and Related Lands Management Measure

The comprehensive evaluation protocol describes water control and restoration as different but equally valid types of water management measures. The traditional USACE water control measure altered watershed hydrology, wetlands and riparian areas. Restoration describes measures to reverse the effects of these past development projects in order to replicate some prior hydrologic regime, to re-create some historic riparian zone or re-flood some drained wetland. These "restoration" measures might require engineering and construction activity and will return some "historic" watershed condition in the riparian zone or in the whole watersheds hydrologic regime.[1] Permanent evacuation is one possible restoration measure, because it allows for a return of the natural hydrologic and ecological functions of flood plains. It should not be the case that evacuation and floodplain restoration are considered as tradeoffs to risk reduction project objectives but as legitimate measures to reach these objectives. Also, evacuation may need to be integrated with other measures to form a complete alternative.

Emphasize the Multiple Outputs of Permanent Evacuation as a Restoration Measure

The comprehensive evaluation protocol recognizes that multiple outputs may accrue from *any* measure, including permanent evacuation. With this understanding, outputs of permanent evacuation should be understood as occurring both on the site and away from the site, to include:

- reducing the evacuated watershed occupants' hazard of flood induced property damage or personal harm
- reducing the costs of flood damage shifted to others (externalized cost)
- reducing the hazard of flood induced property damage or personal harm in other areas of the watershed by altering water flow conveyance or storage at the site of the permanent evacuation
- creating improvements in ecological functions and services from the watershed including enhanced water supply, recreation, fish and wildlife populations, improved water quality parameters, storm water management, as well as other services of interest to watershed stakeholders.

Formulate Plan Increments as Bundled Measures

During plan formulation, measures should be bundled together and evaluated as packages of measures that can address watershed problems and opportunities. There is no inherent reason that measures can not be bundled together as inseparable elements (for example, to maintain contiguous housing and community cohesion) and then evaluated as an increment.

Currently, the USACE evaluation procedures expect that permanent evacuation be justified as an added increment to other measures and that evacuation itself be justified property by property. However, focusing analysis on evacuation in isolation and then on each structure can leave a partially evacuated landscape that may be antithetical to achievement of other planning objectives. An alternative approach would be to "bundle" together structures located in different areas of the floodplain, and to "bundle" evacuation with other measures as alternative ways to address the full range of watershed problems and opportunities. Then incremental evaluation would be made for the bundled measures.

Employ a Multi-Objective Planning Framework

At present, a USACE expenditure must maximize NED subject to meeting environmental constraints set in law and regulation. An exception only can be granted by the Secretary of the Army. Such a narrow perspective would be inconsistent with the comprehensive evaluation protocol. However, the USACE restoration guidance allows budgeting for a project when that project does not maximize NED, if the forgone NED is to achieve environmental restoration outputs. The USACE should recognize that this exemption is the equivalent of a re-introduction of a portion of the *E.Q. account* (environmental quality) as a co-equal objective in the spirit of the 1973 P&S.

This does not mean that the USACE would budget for measures to address all the multiple criteria; however, analyses based on these criteria may be a contribution of the USACE to collaborative planning and shared implementation that has become the goal of watershed planning.

While there are multiple objectives that govern planning, a USACE effort to measure all possible effects under all objectives would strain the analytical resources of the agency. Therefore, the analytical reviews of permanent evacuation should be limited to matters of greatest decision making concern identified in the case studies.

Clarify NED/E.Q. Protocols for Plan Selection

Evaluation in each account is done in relation to specified criteria that require a unique analytical approach. Then tradeoffs among objectives are recognized and made. The tradeoff explicitly described in the restoration guidance is between net NED and E.Q. outputs. If increased E.Q. outputs comes at the expense of NED, the USACE restoration planning guidance calls for an incremental analysis to display and justify NED costs incurred to satisfy increased E.Q. outputs represented in non-monetary terms. The USACE should further clarify some of the measurement approaches that are required to implement this analytical framework.

Review Critical Assumptions Of On-Site NED Benefits for Permanent Evacuation

In considering the *on-site* NED benefits of permanent evacuation the P&G makes the assumption that land market traders have the same hazard information as would be used in a USACE flood frequency and property damage analysis. The P&G also assumes that traders are risk neutral, use the hazard information in the same way as the USACE planners and use the same discount rate in considering future damage costs. The P&G also assumes that the NIP is fully in effect in the area where the permanent evacuation is to take place, mitigating against moral hazard problems from the disaster assistance and flood insurance programs. The practical effect of these assumptions is to support the conclusion that the land market price is fully discounted for flood hazard. As a result, the NED cost of permanent evacuation is the fair market value of the land and improvements. The NED benefits for flood hazard reduction *at the site* are limited to avoided insurance subsidies, avoided administrative costs for the insurance program and the NED value that arises from the new land use (e.g. open space recreation benefits).

Recognize Off-site NED Benefits from Evacuation

Current practice, although not a requirement of the P&G, is to ignore the effects of permanent evacuation away from the immediate site. However there can be hydrologic and economic linkages between the evacuated site and other areas that should be addressed when evaluating the full NED benefits of the permanent evacuation. The USACE should develop guidelines for, and require computation of, such NED benefits from evacuation. As one example recognized by the P&G, property value enhancement from proximity to open space can accrue to

lands adjacent to the evacuated site. Numerous communities have undertaken projects to further develop tourist-based businesses based on "river walks," and river town identities and this may increase property values adjacent to the evacuated site.

Clarify the Opportunities Offered by Individual Project Authorization Language

Conflicts between USACE planning, authorization and appropriations schedules and community desires to reformulate plans often occurred in the case studies. The need for the USACE to move through a sequence of Congressional authorizations for individual projects is well understood. However, the USACE field offices often saw this requirement in ways that created an obstacle to collaborative plan formulation.. Given the broad authorities inherent in any study resolution, the USACE need not secure new authorization to consider evacuation options or restoration of floodplain areas as an approach to addressing water management problems and opportunities.

Contribute to Collaborative Planning

The comprehensive evaluation protocol emphasizes the need to involve all stakeholders and interested parties throughout the planning process. The resulting plan is expected to be implemented by a collaboration among government agencies, non-government organizations and citizens. Of course, the USACE has always worked with a local project sponsor to secure project authorization. Still there have been cases where the USACE was unable to plan in collaboration with others.

Reform Project Level Cost Sharing

At present cost sharing differs according to the output of the project; flood hazard reduction has different cost sharing than recreation, for example. Therefore there is a need to allocate projects costs among the different outputs so that the cost sharing rules can be applied. The USACE will need to develop cost allocation rules that apply to different project outputs when all outputs are not measured in monetary terms.

Conclusion

The USACE traditional planning approaches, if properly applied, can encompass the fundamental elements of the comprehensive evaluation protocol that will be needed to more completely recognize the benefits and costs of permanent evacuation. However, the planning process in the last two decades has become too narrowly focused and inflexible, perhaps in response to restrictive budget and agency priorities. There will need to be new reforms, proposed reforms, and clarification of the reforms that have already been undertaken.

If the USACE moves toward the comprehensive evaluation protocol the challenge will not be one of technical analysis and planning philosophy (the USACE has the tools). The

central challenge will be to understand that the USACE is a partner in a collaborative process of decision making, and shared implementation for a "watershed plan" that may incorporate permanent evacuation as one measure.

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Workshop On Risk-Based Analysis For Flood Damage Reduction Studies

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20-22 October 1997

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Agenda

WORKSHOP
ON
RISK-BASED ANALYSIS FOR
FLOOD DAMAGE REDUCTION STUDIES

20 - 22 October 1997
Asilomar Conference Center
Pacific Grove, California

AGENDA

Day 1

Time		**Description**
Session I: Policy and Present Status		
8:30 - 9:00 A.M.	**WELCOME AND INTRODUCTIONS**	
9:00 - 9:45 A.M.	Paper 1:	**OVERVIEW OF RISK RESEARCH AND DEVELOPMENT PROGRAM** (David Moser, IWR)
9:45 - 10:15 A.M.	**BREAK**	
10:15 - 11:00 A.M.	Paper 2:	**OVERVIEW AND HISTORY OF IMPLEMENTING RISK-BASED ANALYSIS FOR FLOOD DAMAGE REDUCTION STUDIES** (Earl Eiker, HQUSACE)
11:00 - 11:45 A.M.	Paper 3:	**WASHINGTON LEVEL REVIEW PERSPECTIVE OF RISK-BASED ANALYSIS STUDIES** (Steve Cone, HQUSACE)
11:45 - 1:00 P.M.	**LUNCH**	
Session II: Project Studies		
1:00 - 2:00 P.M.	Paper 4:	**AMERICAN RIVER STUDY** (Mike Deering, Sacramento District/HEC)
2:00 - 2:45 P.M.	Paper 5:	**AMERICAN RIVER: LOCAL AGENCY**

		PERSPECTIVE (Paul Devereux, Sacramento Area Flood Control Agency)
2:45 - 3:15 P.M.	**BREAK**	
3:15 - 4:00 P.M.	Paper 6:	**OVERVIEW OF LEVEE PROJECT STUDIES IN ST. PAUL DISTRICT** (Pat Foley, St. Paul)
4:00 - 4:45 P.M.	Paper 7:	**GEOTECHNICAL ANALYSIS PROCEDURES FOR LEVEES** (Tom Wolff, Michigan State University)

Day 2
Time **Description**

Session III: Project Studies (Continued)

8:00 - 8:45 A.M.	Paper 8:	**DES PLAINES RIVER STUDY** (Carolann Biegen, Chicago District)
8:45 - 9:30 A.M.	Paper 9:	**BEARGRASS CREEK STUDY OVERVIEW** (Neil O'Leary, Louisville District)
9:30 - 10:00 A.M.	**BREAK**	
10:00 - 10:45 A.M.	Paper 10:	**COMMUNICATING FLOOD RISK** (Arlen Feldman, HEC)
10:45 - 11:30 A.M.	Paper 11:	**OVERVIEW OF HEC FLOOD DAMAGE ANALYSIS COMPUTER PROGRAM** (Harry Dotson, HEC)
11:30 - 12:30 P.M.	**LUNCH**	
12:30 - 5:00 P.M.	**SPECIAL SESSIONS**	

Session IV: Evening Session: Special Topics

7:30 - 9:00 P.M.	**PANEL DISCUSSION OF SPECIAL TOPICS** (Jaime Merino, South Pacific Division; Bill Fickel, Ft. Worth District; Bob Daniel, HQUSACE)

Day 3

Time	Description
Session V: Risk-based Analysis in Flood Plain Management	
8:00 - 8:45 A.M.	Paper 12: **RISK-BASED ANALYSIS IMPLICATIONS FOR FLOOD PLAIN MANAGEMENT** (Darryl Davis, HEC)
8:45 - 9:30 A.M.	Paper 13: **FEMA FUTURE DIRECTION IN FLOOD PLAIN MANAGEMENT** (Mike Buckley, FEMA)
9:30 - 9:45 A.M.	**BREAK**
9:45 - 10:30 A.M.	Paper 14: **LOCAL PERSPECTIVE OF RISK-BASED ANALYSIS ON FLOOD PLAIN MANAGEMENT ACTIVITIES** (Jim Schaaf, Private Consultant)
10:30 - 11:45 A.M.	**PANEL DISCUSSION: RISK ANALYSIS IN FLOOD PLAIN MANAGEMENT** (Ken Zwickl, HQUSACE; Doug Plasencia, Association of State Flood Plain Managers; Mike Krouse, Institute for Water Resources)
11:45 - 12:00 Noon	**SUMMARY AND CLOSING**